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EDITED BY
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Professor of Agricultural Engineering, Iowa State College

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LAND DRAINAGE

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INTRODUCTION TO SECOND EDITION

During the decade which has passed since the first edition was prepared, a number of notable developments have occurred in the drainage field.

River and flood control have required attention of the national congress; soil erosion and terracing has become a problem of national importance; war salvage explosives have been extensively used in drainage and clearing; drainage in irrigated sections by means of pumping from wells has found wide application; progress has been made in developing pumping and excavating machinery, in building ditches with the aid of a scarifier in connection with running water, and in the use of vertical drainage.

It has been the aim in making this revision to adhere to the plan of providing a concise drainage text, with the least practicable encroachment upon other related fields. Laboratory exercises will need to be modified to fit local climatic conditions, and have not been developed in detail. References indicate sources of further information, and are not necessarily specific citations.

Numerous persons have given valuable suggestions and criticisms, and the authors are especially indebted to S. H. McCrory, M. R. Lewis, Lewis A. Jones and L. T. Jessup for aid of this kind.

W. L. P.

January, 1932

FOREWORD

This book deals with the subject of drainage primarily from the agricultural standpoint, and the subject has been developed largely as a matter of applied soil-physics. Drainage is considered herein as a means of reclaiming additional areas and of making wet lands more productive. Reclamation of arid and wet lands affords the chief means of increasing our food producing areas and drawing a greater proportion of our population into the rural districts.

The present volume is intended, first, as a text book for students of general agriculture or agricultural engineering; second, as a reference book for practical farmers; and third, as an aid to owners of wet, overflowed, marsh, swamp or alkaline land who desire to improve their holdings.

The information presented herein has been gathered by the authors, as farmers, students and instructors, in the Corn Belt States and later in the West, where preliminary feasibility surveys and selection of lands for irrigation projects and drainage projects have been an important feature of our work. Review questions, general references and laboratory exercises have been included to help make up the kind of a book that has seemed to the writers to be needed.

W. L. POWERS

CORVALLIS, OREGON
December 10, 1921

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LAND DRAINAGE

PART I.—FIELD DRAINAGE

CHAPTER I

DEVELOPMENT, IMPORTANCE AND FUTURE OF DRAINAGE

The removal of excess water from wet lands by drainage acquires a more vital importance as a greater proportion of the naturally arable land is brought under cultivation. Wet spots hinder farm operations and transportation in occupied farming areas; and the drainage of such spots grows more imperative as values become higher and agriculture more intensive. The intermittent nature of rainfall, and the variations in soil and topography necessitate artificial control of excess water. The reclaimable marsh lands, in the United States alone, embrace approximately 95,000,000 acres, or an area over twice that of the state of Iowa, while the wet farm land includes several times this area. Opened to settlement and cultivation, this land would increase, to an almost incredible extent, the value of our possible annual crops. The peoples of the earth must be fed; and the drainage of wet but fertile and accessible lands is of fundamental importance in providing food and homes for the increasing population. The public marsh lands in the Central States were largely disposed of a generation ago at \$0.01 to \$1 an acre. These lands, where reclaimed, have acquired a value of \$100 to \$200 an acre. It is evident from these figures that a comprehensive public policy of reclamation should be perfected.

The working out of such a policy will disclose the fact that

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only a part of land reclamation deals with the reclamation of **idle** lands for agricultural purposes. This aspect of the subject has been well expressed in a recent definition of Land Reclamation promulgated by the American Society of Agricultural Engineers: "Land Reclamation involves putting agricultural land to that use in which it will render the largest possible benefits to both the owner and the general public —



FIG. 1. Land practically worthless through lack of drainage.

whether this be the production of crops or the furnishing of recreation — and increasing the benefits to be obtained by the proper use of that land to the highest point commensurate with the cost involved." **Drainage in Europe.** — Stone, brush, and open drains were described in the writings of Cato the Elder, and Columella, the latter of whom lived about 200 B.C.¹ Perhaps the earliest known example of tile-

¹ Roman Farm Management, p. 37, translation by "A Virginia Farmer," Macmillan, 1913, quotes Varro (238-198 B.C.) thus: —

"If the land is wet, it should be drained with trough shaped ditches dug 3' wide at the surface and 1' at the bottom and 4' deep. Blind these ditches with rock. If you have no rock then fill them with green willow poles, braced crosswise. If you have no poles fill them with faggots. Then dig lateral trenches 3' deep and 4' wide in such a way that the water will flow from the trenches into the ditches.

drainage was discovered in 1620, in the " magic garden " of a monastery in France, where the soil was very fertile even in times of drought and the quality of the fruit was remarkable.² Investigation revealed that tile 10 inches long and 4 inches in diameter had been laid in the soil, in such a manner as to form a drain at a depth of 4 feet. Each pipe was funnel-



FIG. 2. Same land shown in Fig. 1, after drainage and growing a crop.

shaped and made to fit into the next one. We do not know how early they were placed there.

A book on drainage was published in 1650, by Captain Walter Bligh, who advocated drainage trenches. In 1764, Joseph Elkington of Warwickshire, England, advocated tapping underground springs along hillsides, and conveying their water away before it came to the surface.

"In the winter surface water should be drained off the fields. On hillsides courses should be kept clear for the water to flow off. During the rainy season at the beginning of Autumn is the greatest risk from water. When it begins to rain all the hands should go out with picks and shovels and clear out the drains so that the water may flow off into the roads, and the crops be protected."

²The senior author recently observed hand-made tile recovered in the course of archeological excavations near Sebastopol, U.S.S.R., that were said to have been made during the Roman period.

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Drain-tile was first used in England in 1810, on the estate of Sir James Graham, in Northumberland. The tiles were made in two pieces, the top being in the shape of an inverted U, and the sole a flat plate upon which the tile was placed. This type of tile was used for thirty years.

The Deanston system of clay pipes was introduced in 1832 by Mr. Smith of Deanston, Scotland. The following year he published a pamphlet entitled " Smith's Remarks on Thorough Drainage." The features of the plan were as follows: 1. Frequent drains. 2. Shallow depth (about 30 inches). 3. Parallel drains at equal distances throughout the field. 4. Minor drains running down steeper places and main drains along chief hollows, with tributary drains for smaller hollows.

A tile-machine was made in England in 1843, and rapid development followed. Government aid has been given, and large projects have been established in Europe during the last century.

Notable European Projects. — Elliott describes two immense drainage projects in the Old World. One of these, the English Fens, embraced 700,000 acres of tidal and overflowed peaty lands which were reclaimed by levees, ditches, and pumping plants. The work covered a period of two centuries and added an area, " dotted by thrifty towns and traversed by railroads of national importance " the gross product of which is worth not less than \$30,000,000 per year.

Haarlem Lake, Holland, is another striking example of successful drainage. The lake formerly covered an area of 43,700 acres. Between 1840 and 1852, the Dutch Government reclaimed this tract by means of immense canals and pumps. It was then divided by means of interior ditches, into fields of 50 acres each. The net land area, 42,300 acres, was drained at a cost of \$5,516,000 or \$128 an acre, and sold to settlers at \$80 an acre. Such a policy is, of course, only possible in a government enterprise, the state being one concern which can afford to improve land when the returns are less than cost plus interest. Some 16,000 people now occupy the reclaimed land, which produces much of the food raised in northern Holland.

The Zuider Zee drainage project in Holland, one of the world's greatest engineering projects, is being constructed by the Dutch Government. It involves the construction of 18 miles of main dike to

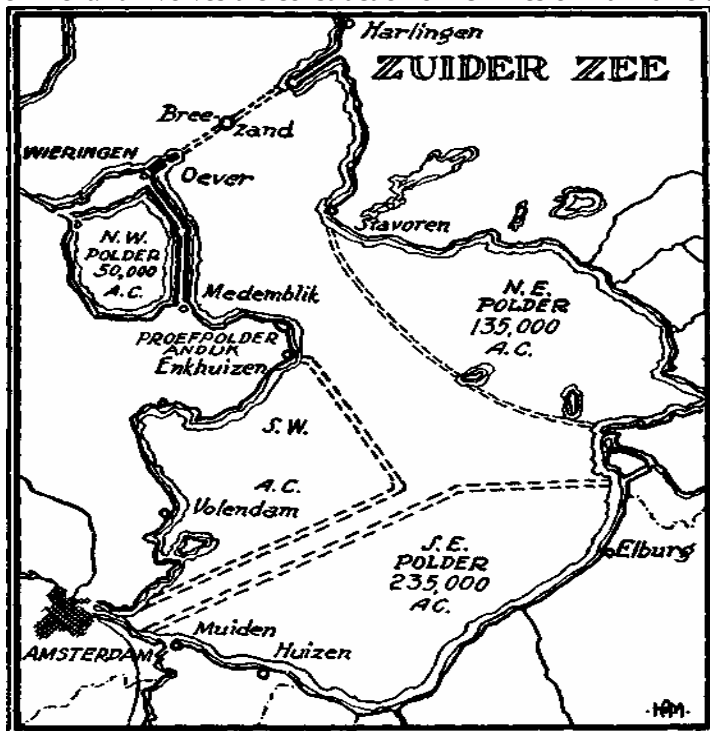


FIG. 3. Outline map of Zuider Zee project, Holland.

hold out the North Sea, as well as tide gates, locks, interior dikes, ditches, and large pumping stations. Most of the land which is to be reclaimed lies 1 to 15 feet below sea-level. This will be unwatered by units or polders in from 4 to 20 years. The project embraces 550,000

acres and its cost will be approximately \$210,000,000. The work will be done and paid for by the state, which expects to repay itself in time and thereafter possess a valuable province capable of supporting a population of 300,000 people.

Drainage in the United States. — Mr. John Johnston of Geneva, New York, introduced tile-drainage into that state in 1835. A drain-tile machine was imported in 1848; and by 1851 Mr. Johnston had laid 16 miles of tile, and so improved a wet clay farm that it was purchased for nursery purposes.

Central Park, New York City, was drained in 1858. It contained 856 acres, and was the largest thorough drainage project undertaken, up to that time, in the United States. In 1867, Colonel Waring, the engineer in charge of this work, published a book reporting mosquito control work entitled " Drainage for Profit and for Health."

Munn in 1860 issued a concise treatise entitled " The Practical Land Drainer," covering the principles and practise of land drainage. He called attention to the use of subsoiling or mole drainage as well as to syphon drainage.

Previous to this date, diking and ditches had been used in the South, in connection with rice culture, and mosquito and flood control. Meanwhile, in the Corn Belt states, the tillable land was increasing in value, and farmers were learning that the wet lands yielded to drainage and became very valuable corn land.

Manly Miles, in a book entitled " Land Draining," called attention to early experiments with drainage gauges and to energy relations involved in evaporation and soil temperature changes in relation to drainage. He was probably the first to call attention to methods of avoiding difficulty from iron oxide deposits in tile-lines placed in peat soil.

Among the outstanding features in the development of drainage in the United States may be mentioned (1) the enactment of district drainage laws, (2) the improvements made during the eighties in machinery for dredging and pumping, (3) improvements in concrete construction, (4) the establishment of numerous tile-factories and the use of larger tile,

(5) the introduction of dynamite as a means of clearing a right of way through wooded land, and (6) the work of research organizations.

During the last decade, important drainage work has been accomplished in the irrigated sections of the West. The U. S. Bureau of Reclamation up to June 30, 1929 had constructed 2250 miles of open and nearly 500 miles of closed drains to relieve or protect 915,284



FIG. 4. Effect of drainage on winter grain, and from undrained area at right. Seedlings from tiled area at left.

acres from seepage and water-logging. Interest in drainage now extends to the Pacific Coast, where tidal overflowed and wet lands are being reclaimed and hundreds of miles of tile are in use.

According to the U. S. Bureau of the Census, the organized drainage enterprises in the United States in 1929 included 84,815,500 acres with a capital investment of \$682,562,441 including 130,457 miles of ditches; 60,231 miles of tile-lines, and 7612 miles of levees. The preliminary summary is given in Table XXV, appended.

Drainage of these lands is regarded as a matter of importance to public health and an inestimable service to agriculture. Every state in the Union contains lands in need of drainage, the areas varying from 8000 acres in Rhode Island to 17,000,000 acres in Florida, where enormous projects have been outlined.

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According to Teele (17), the greatest areas of wet lands are in the states grouped around the Great Lakes and those along the south Atlantic and the Gulf of Mexico, 70 per cent of the area needing drainage being situated in the Mississippi Valley. Crops suitable for these wet lands when drained are in the order of their importance: corn, wheat, cotton and hay crops, sugar beets, cane, vegetables and small fruits.



FIG. 5. Unreclaimed Columbia river bottom near Astoria. (Photo by Brubaker Aerial Surveys, Portland.)

The estimated increase in land values and in annual income from draining the swamps and overflowed lands in the United States is placed at \$1,593,633,155 and \$273,079,295 respectively.

It has been estimated that about 18 per cent of our irrigated lands are in need of drainage. Extensive over-irrigated and alkaline areas, as well as water-logged wild meadows, are re-claimable through drainage and water-control. Drainage of tidal and overflowed lands, and control of erosion and seepage may be accomplished through the use of levees,

tile systems, and pumps.

According to our present knowledge, some 75,000,000 or more acres in the United States will ultimately be reclaimed, while a much greater area can be benefited by drainage. There is a growing interest in drainage throughout the country.

Flood Control. — Restriction of river channels by structures such as bridges and dikes has increased flood heights and damage. Yet, great



FIG. 6. Same locality as Fig. 5, after drainage and improvement. (Brubaker Aerial Surveys.)

works have been built in China, India, Babylonia and Egypt to control floods and deposits of sediment. Notable floods of recent times are still impressed on the memories of the present generation. The flood of March, 1913, in the Miami Valley alone caused a loss estimated at 360 lives and \$100,000,000. The flood on the Arkansas River, June, 1921,

caused the loss of over 150 lives and \$19,000,000 in the Pueblo district. The Mississippi flood, in the spring of 1927, covered 20,000 square miles, or an area twice the size of Maryland, extending from Cairo to the Gulf of Mexico. Half a million people were made homeless. The loss of property was estimated by Secretary of Commerce, Hoover, at \$300,000,000 to \$500,000,000. A relief fund of \$17,000,000 was used. Provision for great flood ways and the strengthening of levees are among the recommendations for improving the situation. Reservoirs and reforestation may help to some extent. Under-drainage of marsh lands renders the soil more absorptive and should tend to equalize runoff.

Recent Developments in Drainage. — Soil erosion has come to be a national problem, and methods of protecting sloping surfaces and stream banks will be considered later. Drainage by means of wells has attained importance as a means of relieving water-logged, irrigated land and of providing water for supplemental irrigation supplies. Building ditches with water aided by sluicing or scarifying devices has recently been accomplished, while the tractor-grader and war salvage explosives have been brought into use to lessen the human labor in drainage undertakings. The commutation method of building up low marshy areas by using them as settling basins for silt-laden water, has been employed successfully. These subjects are to be given special attention later in this text.

Advantages of Drainage Reclamation — We readily spend \$40, \$60, and \$80 an acre to irrigate lands that produce as much by dry-farming as our wet lands yield in their present condition.

Lands that require drainage are generally of good depth, well supplied with plant food, and located where there is a long growing season. As a rule, they are favorably located with regard to markets and transportation and are free from hard-pan or rock. It is believed that much of this wet soil, if drained, would pay a good rate of interest on the total investment. Drainage is a permanent soil improvement and one of the best that can be made in a wet region.

Federal and State Aid. — In 1846, Great Britain created a loan of \$10,000,000 for England and \$5,000,000 for Ireland, to be advanced to farmers for drainage purposes. Repayment is made in annual installments. France has also loaned money and furnished engineering assistance to farmers, while Belgium and Germany have built factories to make tile at low cost.

England permits private improvement companies to construct drains and make loans, which are secured by rentals. France furnishes engineers, free of expense, to farmers. The province of Ontario, Canada, loans as much as \$1000 to a farmer and allows twenty years for repayment, at the rate of \$7.36 annually for each \$100 loaned. Vermont has a similar arrangement.

The U. S. Department of Agriculture, Division of Agricultural Engineering, conducts experiments, makes surveys, and publishes bulletins. The various states conduct experiments, publish bulletins, and give assistance and instruction to landowners through agricultural colleges, experiment stations, and extension service. The experiment stations have conducted experiments with tiling in wet soils and have developed and applied successful methods of draining and improving these lands. Surveys have been made to determine the feasibility of possible projects. The agricultural colleges, through their extension service, conduct field demonstrations, design field tile systems, demonstrate the use of ditching machines and assist in the organization of drainage districts. Public sentiment is becoming more favorable to a comprehensive plan for reclamation. Numerous reclamation measures have been introduced in Congress and a comprehensive national policy of reclamation may be expected to develop before long.

Drainage Organizations and Institutions. — State drainage district laws have developed and made possible community and district drainage enterprises extending over millions of acres in some states.

The National Drainage Congress was organized in November, 1911, in Chicago. It is composed of engineers, landowners, capitalists, and others interested in drainage. Several states, including New York,

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Louisiana, Wisconsin, Iowa, and Oregon, have drainage organizations which meet annually; and the reports of their proceedings are valuable. There are also some important flood-control commissions. These organizations are affiliated, and strive to aid drainage development by providing publicity and proposing needed legislation.

QUESTIONS

1. What conditions give rise to poor drainage?
2. Why is drainage of public importance?
3. What records are there of early drainage in Europe?
4. Describe some large European projects.
5. What improvements have aided drainage development?
6. Where and when was tile first used in America?
7. State the advantages of drainage.
8. Outline past and present drainage measures.
9. What aid is given in land drainage by the experiment stations and by extension service?
10. What organizations and institutions have assisted drainage development?
11. What losses have been incurred from great floods in recent years?

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CHAPTER II

BENEFITS OF DRAINAGE

The benefits of drainage consist in improved soil, plant and water relations. Drains are installed to increase crop production and to enhance the value of wet land. The following are the main reasons why drainage increases the productive capacity of the soil.

1. *Removes excess water.* — The primary object of drainage is to lower the water-table, or remove the excess free water in the soil, so that the larger pore spaces may contain some air. The drainage-water can frequently be used for stock water or irrigation.

2. *Increases the capillary supply of moisture.* — A drained soil is in a better state of tilt than one in need of drainage, and therefore contains more pore space and more room for air and for usable soil-moisture, or capillary moisture. When the water-table has been lowered, there exists a deeper zone in which capillary moisture can be stored and used by crops.

3. *Improves the soil-structure.* — Drainage is of great assistance in improving the soil-structure. It permits the soil to be worked when it contains the proper amount of moisture to make it crumble into a mellow state on being plowed. Drainage allows plants to root deeply, and form fibrous vegetable matter in the subsoil. This causes a mellow structure and facilitates cultivation.

4. *Increases the root-pasturage.* — If a water-table which is within 1 foot of the surface is removed by drainage to a point 3 feet below the surface, the zone for feeding roots is thereby trebled. This enables plants to develop deep roots and acquire more resistance to drought. Drainage frequently makes it possible to establish deep-rooting crops. For this reason, well-drained land contains more moisture in time of drought.

5. *Affords better air circulation.* — Removing the free water from the large empty spaces in the soil makes room for more air. If the water is kept moving downward and out through the soil, additional air is brought into the soil by suction. Moreover, the presence of drains brings air into contact with the soil, and is an aid in aeration and the liberation of plant food, making it possible to use fertilizers to better advantage.

6. *Makes soil warmer.* — A wet soil is a cold soil, because the temperature is lowered by excessive evaporation at the surface. Drained soil is warmer and permits better and earlier germination. Experiments at the Oregon stations have shown soil to be from 3 to 8 degrees warmer when drained.

7. *Lengthens the growing season and firms the soil.* — Drainage makes the soil firm earlier, so that the whole field can be worked at the proper time. It makes possible the raising of legumes or long-season crops and cultivated crops where formerly only grasses, swamp growth or weeds existed. Ontario Agricultural College found that a large number of fields, on which reports were made, were planted from one to six weeks earlier after being drained.

8. *Assists decay and nitrification.* — Those soil bacteria which cause the decay of vegetable matter and aid in nitrification require the presence of oxygen and nitrogen in the soil. As these two elements must be obtained from the air, good aeration is necessary to the work of nitrification. In water logged soils, denitrifying bacteria, instead of nitrifying bacteria, are at work.

9. *Prevents erosion.* — Drainage permits the excess water to pass through the soil instead of over it, so that plant-food is carried into the subsoil and held there. In poorly drained areas, runoff removes the most valuable soil from the surface.

10. *Diminishes the effect of drought.* — Crops on drained soil are better able to withstand the drought, because the soil is in better structure or tilth. It contains more vegetable matter from deep roots; it has a larger reservoir for usable soil-moisture; and the plant roots are consequently deeper. Well- drained plots on the Oregon Experiment Station, at the close of the dry season in September, 1916, were found to

contain an average of 2 per cent more moisture than adjoining plots with similar crops and poorer drainage.

11. *Prevents heaving and freezing out* of clover and other plants of this character. In wet soils freezing and thawing causes the crowns of the plants to be lifted, and the roots exposed to the cold weather.

12. *Prevents the rise of alkali.* — Where there is natural underdrainage, or artificial under drainage at a suitable depth, excess soluble salts are kept moving down and out through the drains, so that alkali does not accumulate. Soil acidity or toxins may be removed or its increase largely prevented by drainage.

Toxic substances may develop under conditions of poor aeration. Unoxidized organic compounds of an acid nature, reduced forms of iron, or aluminum in reactive (ionized) form, may interfere with crop growth and give rise to the use of the term "bog toxins."

In addition, drainage improves sanitary conditions, promotes healthfulness and is an aid to transportation and to the general development of a country. Timely drainage pays big interest on the money invested, by increasing the yield and the value of the product.

Drainage Benefits Swamp Forests. — Studies of drainage as affecting forest growth (15) indicate that removal of excess water from nearby forest areas promptly increases such growths as spruce and cedar. The pulp wood and cedar pole producing power of such stands is reported to be increased three or four times through drainage. Experiments are under way in the Lake States to study the exact effect of the removal of excess water from swamps on timber growth, and to learn the most competent and economical methods of doing this work. A bowl-shaped fibrous sphagnum peat bog in Minnesota was greatly improved by an outlet ditch and intercepting laterals.

Successful Drainage Practice. — A circular letter was mailed to a list of farmers in western Oregon who had tiled their land. The purpose of the letter was to learn something of the extent and success of tile-

drainage. About fifty replies were received, over forty of them giving answers to the questions asked.

The replies came from farmers who had had from three to thirty-five years' experience with tiling in the "white land" and other common soil types of the Willamette valley. The reports cover experience with approximately 100 miles of tiling, draining several thousand acres of low land and costing, for the total area affected by the drains, about \$10 an acre.

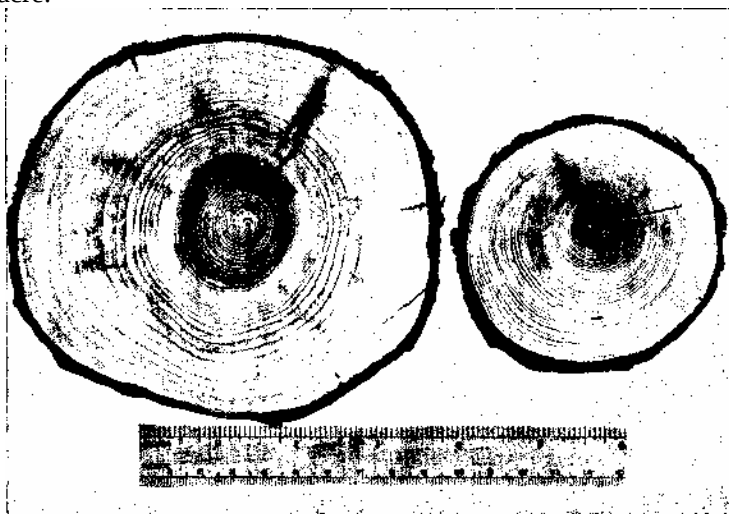


FIG. 7. Effect of drainage on growth of cedar. (Courtesy of Division of Agricultural Engineering, University of Minnesota.)

The average fall reported for drains in operation was about 1 foot for each 100 feet. Eighty per cent of the tiling was laid by water grade, while the rest was laid with the aid of a surveyor's level.

The average wage for digging trench and laying tiles for 4 inch laterals, 3 feet deep, was reported as \$0.30 a rod. Most of the ditches were refilled by the use of a plow with a long evener. Under fair soil and weather conditions, the amount dug and laid each day averaged

about 100 feet for each man. Under good conditions as much as 1 rod an hour was installed.

Question 23, in the circular letter, read, " Has your drain system handled the excess water as well as expected? " Thirty-nine farmers answered this question. Thirty-six of these replied "Yes"; one replied "Better"; one replied "Yes, except in small lateral"; and one stated that tiling " did not handle flood-water as expected."

Question 24 read, " Has drainage improved your soil?" Twenty-nine replied " Yes." The other replies to this question



FIG. 8. Oats on reclaimed tide land, Skagit County, Washington.

were as follows: " Wonderfully," " Very much," " Indeed it has," " Greatly," " As far as completed," " Too soon to tell."

Question 26 read, " Do you consider that drainage pays under your conditions? " Thirty-seven answered " Yes." The other replies received were " Decidedly," " Certainly," and " It pays big." There was no negative reply.

Question 25 read, " Can you cite any definite results?" Replies to this question were generally favorable, and some should prove of interest. One replied " One hundred per cent better"; another, "Soil can be worked earlier in the spring." Other replies were as follows:

" We lost 150 prune trees out of 500 set out before draining, and only 300 out of 7400 set out after draining."

" Before draining, water stood on the field all winter; but now it drains after only two days."

" The land is dry enough to farm and produce good crops, where before draining it was waste."

" Yes, one-half of the field could be used only for spring crop, and then dried out hard as a bone. Now, with drainage, it is better than the other fields."

" Yes, land that formerly did not pay taxes now produces good crops. I consider that tiling has doubled the output of the farm, and the system is not yet completed."

" We get fair crops now, and obtained nothing before drain-ing."

" Land can be worked more conveniently and earlier."

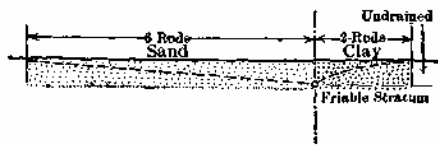


FIG. 9. A comparison of the effect of drains in sand and in clay.

" Yes, could not raise winter wheat on the land previous to tiling; since tiling winter wheat does well."

" Yes, we can plow wet spots a month earlier on some soils."

" I put in about 3000 feet each winter. One-year-old ditches are drying the ground about 10 feet wide, two-year-old ditches 20 feet wide and three-year-old ditches 40 feet. I had black soil that was hardly paying taxes before tiling. Since tiling, I have fine corn, clover and kale, and not any water. It would be best to come and see the real benefit. There is but little wet land in this section that it would not pay to tile."

" Our drainage system is fifteen to thirty-five years old and handles the excess water so that ground can be plowed after we have had two days of clear weather following any hard storm. The drainage system has improved soil fully one hundred per cent."

" After the soil is thoroughly drained, it becomes very porous and will

hold the moisture in dry weather fully one hundred per cent better. The soil becomes warm and the rootlets of crops can penetrate the soil a great deal deeper."

" I am more than satisfied with my drains. The main drawback to drainage is lack of funds. I am putting in about 3000 feet more this winter. Last summer I raised corn 8 feet high

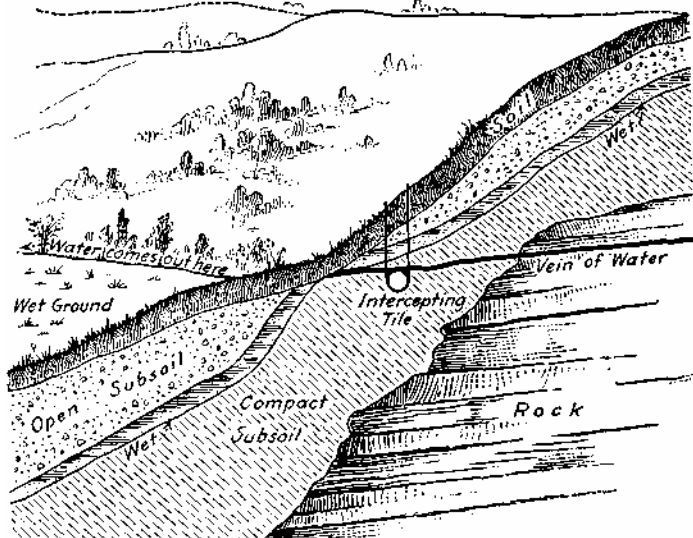


FIG. 10. Sketch showing the effect of impervious soil stratum upon drainage, and the use of intercepting tile.

on what was the very wettest part of my farm before draining; and my oats were doubled in yield. Three neighbors are putting in a little tiling as a result of my making a start last winter."

" Yes, land that formerly did not pay taxes now produces good crops. I consider that tiling has doubled the output of my land and the system is not yet complete. I certainly do consider that it pays."

" Yes, where once was a swamp I now raise 50 to 90 bushels of oats to the acre."

" Indeed, I have drained my land with success; I would rather have

160 acres of drained land than 320 untrained, if I had to live on it and farm it."

Profits from Drainage. — Timely drainage usually pays in increased crops and increased land value. Those who have drained say that it pays. The writer has examined most of the tile systems in use in Oregon and

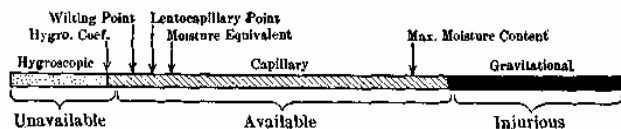


FIG. 11. Diagram showing forms of soil moisture, and important moisture points.

many systems in the Central States; and, while a few drains in use are too small or too deep, or have been poorly constructed, he has failed to find a tile system properly installed which has not been successful.

Tile-drains usually improve for years. If properly installed, they should increase the value of the land by an amount equal to their cost.

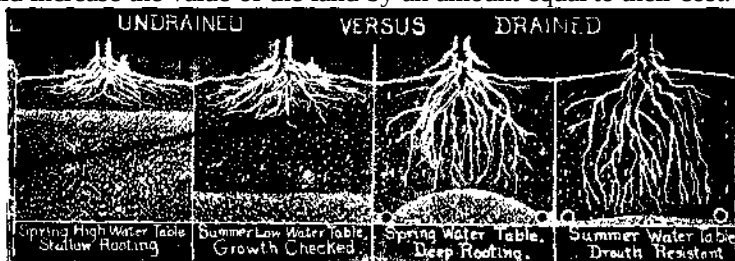


FIG. 12. Effect of drainage on the roots, and drought.

The profits from drainage are so large that drains frequently pay for themselves within a few years. It costs money to hold wet land and most of our wet farm lands will pay a better rate of interest on the total investment if drained. Drainage is a permanent improvement; it is the fundamental step in the improvement of our wet lands; it makes

rotation with soil-building crops possible and constructive soil treatment effective.

It has been estimated that at the present rate of tile installation it will take 300 years to drain our wet farm lands. This advance is too slow and will not be of much benefit to the present generation.

QUESTIONS

1. Name twelve agricultural benefits from drainage.
2. What non-agricultural benefits result from drainage?
3. Explain how tiles remove excess water.
4. Give reasons why drainage increases the space available for usable soil moisture.
5. How does drainage increase root-pasturage and resistance to drought?
6. Why is air necessary in soil, and how does movement of free water affect aeration?
7. Why is unsaturated soil firmer?
8. What conditions are necessary for decay and nitrification?
9. What is "heaving," and how is it controlled by drainage?
10. How does drainage aid control of soluble soil acid or alkali?
11. Give examples of successful farm drainage.
12. In what ways may profits be realized from drainage?
13. Under what conditions may "bog toxins" occur?

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CHAPTER III

THE RELATION OF SOILS TO DRAINAGE

Surface Geology and Drainage Conditions. — Drainage is concerned largely with two materials, soil and water. All soil must have drainage to remove excess water; but in many cases the land has natural drainage, through channels cut out during the formation of the earth's crust. Where the country is geologically old, running water has usually cut out natural drainage channels and completed valleys, so that there is

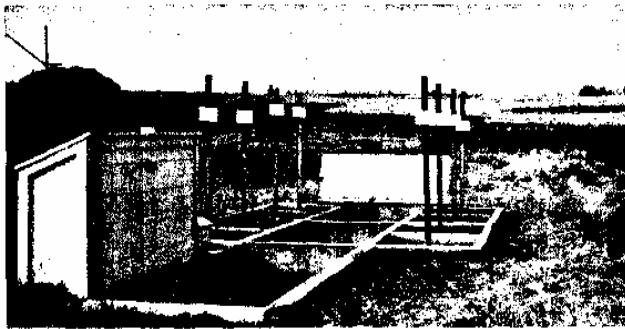


FIG. 13. Lysimeter or drainage gages, Umatilla Branch Experiment Station, Oregon.

comparatively good natural drainage and artificial drainage is not needed except to control erosion.

The geological conditions giving rise to poor drainage are as follows:

1. Bodies of rock formed by faulting of the earth's crust, or by lava flows, often temporarily obstruct the natural drainage system of a country. A water course is frequently divided into three parts, the upper, middle and lower valleys, in all of which the stream is more or less meandering. Between these divisions the river cuts through rock and is

confined to a narrow canyon, where it has little or no effect on the drainage of the region.

2. Shale ridges are common in the hill lands of the Pacific Coast region and in the bench lands in the interior valleys. Former inland seas or lakes developed shore lines which remain in the form of shale ridges in the subsoil.

3. Heavy clay occurs in the subsoil as a uniform layer, or as hogbacks or dikes. In places, the hard clay subsoil may be in the shape of pockets. These dikes and pockets interfere with the subsoil drainage, and cause water-logging of the subsoil and seeped spots on the surface. Frequently the topography of the surface is very uneven and is hard enough to interfere with drainage, some rather firm material being present in the subsoil.

4. Beaver-dams or accumulations of fallen logs and other vegetation may interrupt the outlet of a flat area and give rise to a growth of marshy material. Frequently the vegetable matter accumulates under water faster than it decays, giving rise to an organic soil. Silt deposits may help to complete such an obstruction.

5. Moraines interrupt the surface drainage of the glaciated country. Odell Lake and other lakes on the east side of the Cascades are glacial lakes formed in this way. Old Lake Kankakee, or the Kankakee Marsh, in northeastern Illinois and northwestern Indiana, is a great marshy area of this kind that has been largely reclaimed by drainage.

6. Large areas of low-lying land or flat land with retentive subsoil will require artificial drainage, if the climate is wet.

7. Tidal and river bottom marshes.

Effect of Soil-Texture on Drainage. — Normal soil is inorganic material mainly derived from the weathering of rock on the earth's surface. It is classified, according to size of the component particles, into sands, silts, and clay. Sands and sandy loams, or those soils which are free-working, are usually naturally drained or when artificial drainage is necessary, can be readily drained by means of a few deep drains placed rather far apart. The fine-grained soils, like the clays, have

a great surface area, and their pore space is very finely divided. Owing to the friction developed by the small particles which compose them, these soils take up water very slowly and hold it stubbornly. Clays are also inclined to puddle.

Heavy Clay. — Adobe, locally called "sticky," is a heavy clay soil containing 40 per cent to 60 per cent clay. It occurs in many valleys in the Southwest and in the Pacific Coast region, as well as in other sections. It is doubtful whether thorough underdrainage of these sections is at present justified. Surface drainage can be provided within the "sticky" areas, and the water can be cut off before it reaches them. The clay subsoil under the "white lands" of the Willamette valley is very putty-like and renders this soil difficult to drain. Similar areas of retentive soil occur in Missouri. Drainage of tight clay in the South Central States is also extremely difficult. In dealing with areas that have a heavy clay subsoil, it is best to locate the drain over, under or around these areas as much as possible, picking up the water before it reaches the retentive soil, or, if they are saucer-shaped areas, providing catch-basins in the lowest portions. These catch-basins will permit the water to enter the drains more readily.

Occasionally we find a sand-clay, or a soil that contains a very appreciable amount of grit but is cemented together with clay so that it is very putty-like and difficult to drain. Collecting wells may be useful in such soils to bring water to the tile. Drainage is the first step in the improvement of these retentive soils; it is necessary before lime or other fertilizers can become effective. We should drain first and then use lime, manure, and deep tillage.

Colloidal Clay. — The soil constituent that makes drainage most difficult is the fine ultra clay or colloidal (jelly-like) fraction which is the seat of life of the soil, as differentiated from the coarse soil material. The individual particles of colloidal clay are seen only with the ultra microscope and are one thousandth to one hundred thousandth of a millimeter in diameter or less, approaching the size of complex molecules. Like other colloids, ultra clay particles have an enormous

surface area, great absorptiveness, and marked swelling properties; will absorb and hold bases such as calcium ion on their surfaces in loose electro-chemical combination and remain in suspension in water indefinitely. Absorption is used as a measure of colloids in soils. The higher colloid content makes soil hard to work.

A calcium clay may be friable due to the flocculating effects of the calcium, while a sodium clay (black alkali) will be de-flocculated, causing soil to "freeze up" and become impermeable. Chemicals such as sulphur will need to be applied to "black alkali" to cause neutralization and flocculation before salts can be successfully leached out.

Swelling caused by a shower, according to Matthews, may check penetration of later rainfall into a rather dry soil, or de-flocculation may cause the rate of percolation to decrease with continued rainfall. This deflocculation is favored by reduction of the concentration of the soil solution as leaching proceeds. Water imbibed or held by force of attraction in and around the particles, gives rise to volume changes upon wetting and drying. Repeated wetting and drying in hot weather may cause precipitation of certain colloids in alkali soil and improve permeability. Drainage may prove inadequate unless aided by intelligent cultural practises and sometimes chemical treatment.

Organic Soils. — Deep peat soil is easily drained where outlets are available, and makes good land, although it may need chemical treatment. If shallow, a sand or shale substratum facilitates drainage more than silt or clay.

Muck contains decayed vegetable matter and silts, and requires more thorough drainage.

Effect of Soil-Structure on Drainage. — Soil particles usually occur in clusters. Where the soil is in good tilth there are pore spaces between the individual soil particles in a cluster, and larger pore spaces between the clusters, as in popcorn when it is mixed with syrup. In a puddled condition, the soil particles are dove-tailed together and the finer particles filtered in between the coarser ones, so that there is a minimum of pore space and a maximum density, the arrangement being

similar to concrete. In a water-logged soil, the cementing materials have been dissolved, and, as the soil is saturated, the films of moisture, such as hold moist beach sand together, are eliminated, and the soil yields like dry sand or sand under water. Under these circumstances there is nothing to support the soil-structure and it collapses, allowing the particles to run together. Bad structure makes soil slow to drain and, conversely, an improvement in drainage works a corresponding improvement in soil-structure and gives stability to the soil.

Importance of Subsoil Examination in Drainage. — Under-drains must operate in the subsoil; and, from a drainage standpoint, the subsoil is more important than the surface. In most of our wet lands the subsoil lacks aeration, is lighter in color, finer in texture, and contains less organic matter than the surface. Excessive moisture has prevented crop roots from penetrating into the subsoil as they would if the soil were drained. Heavy substrata must be located by the use of a soil-auger and the tiles must be located in the free-working soil, avoiding these heavy strata as much as possible. Occasionally, it will be necessary to cut through a hard substratum so as to provide an outlet and dispose of the excess water by means of gravity.

The subsoil of an arid district is different from that of a humid soil in that it is less uniform, and is more apt to contain alkali hard-pan or gravelly strata. The wet soil of a humid climate usually develops a system of tiny veins through which water travels. Such a system is little developed in arid soil.

Soil Development and Drainage. — Soil material, such as a recent alluvial deposit, is frequently uniformly open and permeable. As this material ages, percolating water may remove some soluble and colloidal materials from the surface soil layers or horizons, and these may accumulate in a lower horizon, causing a more compact impervious condition as the soil profile matures. An aged soil profile may come to have a " clay-pan " under humid conditions or a " rainfall hard-pan " under semi-arid conditions.

Effects of Hard-Pan upon Drainage. — Hard-pan in the subsoil is caused by the deposition of substances from solution. It occurs where percolation ceases, and interferes with the movement of free water, causing at least a local water-logging of the overlying soil. In some cases the hard-pan may be broken up with dynamite, and vertical drainage may be established. In other cases, hogbacks in the hard-pan can be cut through, so as to afford a drain that will remove the water. Common cementing materials found in hard-pan soils are colloidal clay, lime, iron, soluble alkalis, and silicates. Lime acts as a powerful cement in combination with humus. Plowing to uniform depth or pasturing with sheep in wet weather may puddle the soil at the bottom of the furrow-slice and cause a "plow-sole," which interferes with drainage. Artificial drainage will frequently renew percolation, rediscover the cementing material and correct the conditions which have hindered natural drainage.

Slacking of subsoils, when they are thrown out of the drainage ditch or exposed, is due to shrinkage of the clay contained, oxidation of the minerals, and probably also to a rearrangement of the soil-moisture films.

Lands Needing Drainage. — Following the classification of wet lands by King, our wet soils may be grouped as follows:

- (1) Nearly flat lands where water from surrounding uplands collects. Ponds are in this class.
- (2) Areas adjacent to higher lands, permitting seepage. Steep hill lands in humid sections and the seeped alkali lands in the irrigated valleys of the arid region are in this class.
- (3) Lands inundated regularly by overflow from rivers or tides. The wet lands along the coast, lower flood-plains of large streams, and the lands in the marshes surrounding lakes may be included in this class.
- (4) Flat lands in wide areas underlain by a retentive subsoil. "White lands" are of this class.

- (5) Irrigated cranberry marshes, rice lands, etc., where an excess of water is applied and must be removed again.

Preliminary Studies. — The first step in laying out a drain system is to make an examination of the soil and subsoil conditions by the systematic use of a soil-auger. This will reveal the presence of gravelly strata through which seepage travels, or of hard strata over which seepage-water is moving. Putty-like layers will also be located in this way, and the drains can then be located over, under or around these layers, so as to collect the water in spite of the retentive areas in the subsoil, and convey it away as directly as possible.

QUESTIONS

1. What geological conditions cause poor drainage?
2. Explain the relation of soil-texture to drainage.
3. Describe the characteristics and drainage qualities of adobe, sand, clay, peat, and muck.
4. Distinguish between puddled structure and good structure.
5. What is the relation between texture and structure in soils?
6. What is the relation between soil-structure and drainage?
7. What substances cause hard -pan?
8. How does hard -pan affect drainage?
9. What is a "plow-sole," and how does it affect drainage?
10. How should subsoil examinations be made and what points should be noted in making them?
11. Compare the soils of humid and arid regions with regard to the character of the subsoils.
12. What different types of localities need artificial drainage?
13. How can the drainage requirements of a field be determined?
14. What causes slacking of subsoil when exposed?
15. How should tile be located with reference to sticky soil bodies?
16. Explain the meaning of soil colloids and their relation to drainage.

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CHAPTER IV

RELATION OF SOIL-WATER TO DRAINAGE

Forms of Soil-Water. — In drainage we deal with gravitational water, or free water, a form of water which may be seen to move downward through the soil by means of gravity. It is the water that fills the larger pore spaces and causes soil to be saturated or water-logged. Most field crops will not do well with their roots in saturated soil. Crops can tolerate more or less free water, if it is kept moving, or is "live water," and contains some air. Water may become usable soil-moisture after it has been drawn up by capillarity into the soil above the plane of saturation or water-table. It is then known as capillary water. The water-table is also called "water-plane" and "sheet water." The amount of moisture in soil decreases with distance above the plane of saturation. Near the free water is a wet "capillary fringe." Forms of soil-moisture and important moisture points are indicated in Fig. 14.

Soil-Water Movement. — Soil-moisture movement is due mainly to surface tension and gravity. The movement is modified by temperature, confined air, substances in solution, texture, structure, pore space, colloidal swelling, hydrostatic head, and other factors. When in equilibrium, the measure of the upward-acting force due to surface tension in balance with the force of gravity is called "capillary potential." When gravity and surface tension work in the same direction, the rate and amount of movement are greater. In cooler soil the surface tension is greater, and moisture will thus be drawn from warmer soil having the same moisture content. In drier soils the films of moisture are more tightly held and have sharper curves and will draw moisture from more moist zones.

It is now thought moisture movement by capillarity is less important and that the root goes to moisture rather than that moisture goes to the

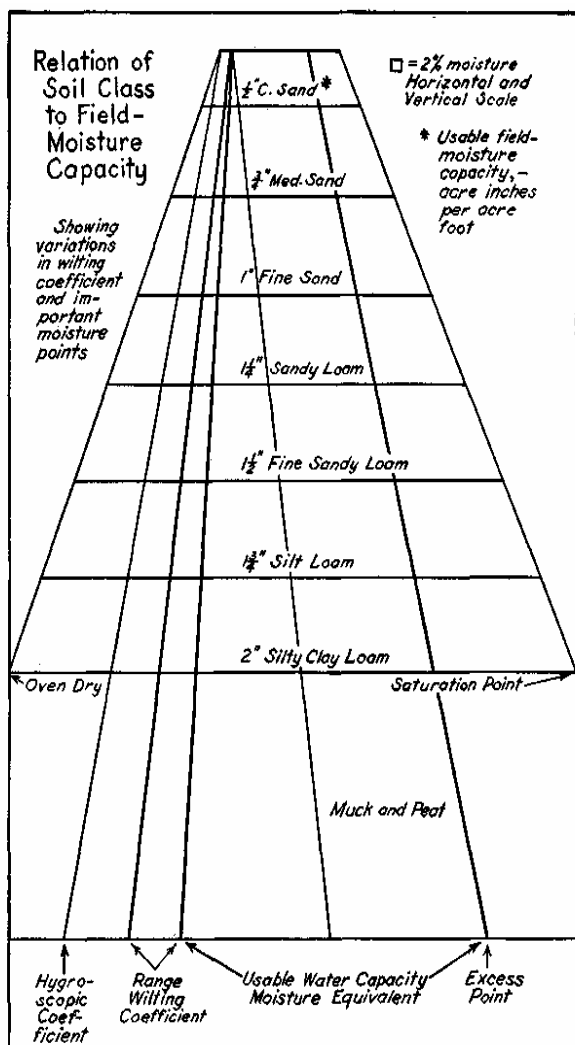


FIG. 14. Relation between soil classes, usable water capacity, and their important moisture points. The linear relation does not hold strictly for coarse soils.

root. Mulching saves little water but kills weeds, aids nitrification, and corrects soil structure. More water is present and little is required to saturate wet soil in the " capillary fringe " just over a water-table.

Free water penetration is greatest into soil at optimum moisture content. The flow of air through soil has been measured to estimate effective diameter and porosity.

The rate of flow of soil-water depends mainly on the available head or gradient, relative porosity of soil, and temperature. In Table I, summarized from U. S. Geological Survey data,¹ the velocity of flow is based on a fall or grade of 100 feet to the mile, a porosity of 32 per cent and a temperature of 50° F.

TABLE I. — RATE OF FLOW OF SEEPAGE-WATER AS AFFECTED BY SOIL-TEXTURE

Kind of Soil	Diameter of Soil Grains, mm.	VELOCITY	
		In Feet a Day	In Miles a Year
Silt	0.01	0.0038	0.00026
Very fine sand	0.05	0.0923	0.00638
Fine sand	0.10	0.3690	0.02551
Medium sand	0.25	2.3050	0.15940
Coarse sand	0.50	9.2240	0.63770
Fine gravel	1.00	36.9000	2.55100

Toleration of Water by Crop Roots. — If the water-table is near the surface the plants will not send roots into it, but will be shallow-rooted. If the water-table rises and remains close to the surface, the roots will be rotted off. Alfalfa usually dies out in three or four years if the water is less than 4 feet from the surface. Grain, red clover, onions, and potatoes need about 3 feet of unsaturated soil to mature well, and Alsike clover, 18 to 30 inches. Rye-grass, redtop, and timothy will grow with 12 inches of soil above sheet water, but are apt to give way to water-grasses and less desirable growth.

¹ Fortier, S. H. Use of water in irrigation.

Water-Table Observation Wells. — A series of borings or small wells is often installed in a regular line or at selected points, to aid in the study of underground water conditions. Temporary borings made with a soil-auger can be used in some soils; but the auger will puddle the soil somewhat and the exact elevation of the ground-water cannot be determined for several hours. However, the character of the soil and the source of the water may be indicated by the boring; and notes should be taken of the core as the well is made. The elevation of the surface at each well can then be determined with a level and, at regular intervals thereafter, readings can be taken of the water-stage in each well. A graduated hollow tube may be used to determine accurately the depth of soil above water. Placing the mouth to the tube and breathing gently as the latter is lowered into the well produces a gurgling sound as the tube reaches the standing water. The depth at which the water is encountered can then be measured on the rod and recorded. More permanent wells have been made by lining deep post-holes with small tiles and filling in around them with gravel. Galvanized down-spouting or old wrought iron pipe may be perforated and used for lining water-table observation wells. Observations may be made in domestic wells.

Fluctuations in Water-Table. — Much information can be gained regarding ground-water conditions at different seasons, by inquiry regarding domestic wells in a settled locality. The water-table may be local or general. The open substrata of a river valley may contain a general underflow closely related in elevation to the river, and somewhat related to the topography of the valley. A local water-table, due to seepage or irrigation may be encountered below a spring or over impervious strata. A temporary water-table occurs in the wet season over low areas. Such a water-table varies slightly with topography and is modified by the source of the water or by dense soil bodies. A tile-line or ravine below the level of the ground-water will tend to lower the water to a broad sloping plane on each side. The gradient of this water-plane may rise 1 foot in 100 feet in loam soil, and be nearly uniform;

while in clay it may rise 1 foot in a lateral distance of 25 feet, and assume a curve with shorter radius closer to the tile. Surface evaporation and growth of plants tend to reduce the water-table, while irrigation or heavy rainfall causes it to rise.

Tracing Seepage. — One method of tracing seepage for short distances is adding a dye to water at the point of disappearance and noting the place or channel where the color reappears. A second method of tracing the movement of underground seepage is adding an electrolyte or soluble salt that will ionize and improve the electrical conductivity of the soil water. Borings are made at various places down the slope and electrodes inserted. Conductivity readings will indicate when the salt solution reaches the electrodes and will show the direction and rate of seepage. A third means of determining the source or direction of movement of seepage is afforded where the temperature of water is different from different sources. A systematic observation of ground-water temperature will then aid in locating the source of damaging water and of designing corrective drains.

Supply of Soil-Water. — The source of soil-water is precipitation, and the initial amount depends upon the amount and distribution of rain. The drainage student should inform himself by means of climatologically data issued by the Weather Bureau and water-supply papers issued by the U. S. Geological Survey, as to the amount and distribution of rainfall and runoff in the localities in which he is interested.

Writers on climatology divide the rainfall year into three periods: first, a period of storage and excess; second, a period of growth; third, a period of replenishing. These begin about December 1, May 1, and September 1, respectively. From an agricultural standpoint they may vary somewhat with the locality.

In a wet climate excess water comes more directly from the sky. In irrigated lands it consists of water which has been stored and used for irrigation, and moves nearly horizontally in the form of seepage-water. In regions where the soil stores almost all the rainfall, as in the dry arid sections, there may be no excess to drain off, so that no

drainage problems develop.

In drainage operations we have to deal with excess rainfall, rather than with average rainfall. For example, at Corvallis, Oregon, where the mean annual precipitation is 42 inches, as much as 12 inches of rain may fall in one month, and as much as 2 inches in twenty-four hours, although there are but few days in the winter when more than 1 inch falls in twenty-four hours.

Drainage systems may be divided on the basis of effectiveness, into three classes. A first class drainage system disposes promptly of excess water resulting from mean maximum rains. A second class, or fairly thorough, land drainage system disposes of excess water except for a few days of the year. If drains in Willamette Valley have the capacity to handle 1/2 inch of runoff an acre, each twenty-four hours, they are adequate for agricultural purposes. A third class drainage system removes excess water within a reasonable time after clear weather sets in.

Effect of Drainage on Usable Water Capacity. — Usable soil-moisture occurs mainly in capillary form. It is not always most abundant in the region of greatest rainfall, for the soil of the wet climate may dry and bake quickly after rains. A water-logged soil has a small amount of pore space, and does not retain moisture well in time of drought. When a soil is water-logged, the fine particles filter in between the coarser ones, and pore space is reduced to a minimum. The cementing materials that bind the particles in clusters are dissolved; the film attraction of soil-moisture is eliminated, and the soil-structure breaks down. Drainage removes the excess water, makes more room for usable water, and permits aeration and growth of feeding roots, which aid the formation of a good structure in the soil. In a drained soil, the improved soil-structure and the development of deep roots increase the water capacity; and a drained soil actually has more usable moisture and more resistance to drought than an untrained or wet soil.

Disposal of Surplus Water — Excess water may be removed by surface runoff, percolation, evaporation, or transpiration.

1. *Runoff.* A large percentage of the excess rainfall may escape by runoff over the surface. The amount of runoff depends on depth of rainfall, on the season and the weather conditions, on topography, on the size, shape and location of the watershed, on geological formation and soil characteristics, and on the amount of evaporation and transpiration taking place in plants. A greater proportion of the rain-water will run off when the soil is saturated, as in the winter and early spring. More will run off if the ground is frozen when the rain occurs. The amount of runoff also depends on the openness of the soil. The runoff from a large watershed in a humid climate varies from 1 to 3 or more second-feet per square mile as a yearly average.

2. *Percolation.* Free water percolates downward through the soil or seeps nearly horizontally through porous strata to lower levels. Writers classify the movements of percolating water according to the zones in which they take place. There are three such zones: first, the unsaturated zone, through which the water moves by percolation to the water-table; second, the surface zone of flow, which is represented by the shallow water-table of the winter season, and shallow surface drains; third, the deeper zone of flow, which gives rise to deep wells, artesian wells, and springs.

The rate and amount of percolation depends, as already explained on (1) soil-texture and (2) structure. The presence of (3) organic matter and (4) lime aids in cementing soil particles into granules, while (5) plant roots and (6) burrowing animals leave passageways for water. (7) Shrinkage cracks in clay soils are effective at the beginning of the wet season. Changes in (8) temperature affect the viscosity or ease of movement of water to some extent, and periods of low (9) atmospheric pressure cause some increase in flow from springs or under drains. Movement of soil-water to tile will be facilitated where soil conditions are favorable to a good rate of percolation, and where there is a greater

head due to deep tiling or a steeper ground-water gradient.

Drainage gauges or lysimeter tanks have been used in numerous places. Records have been obtained at Rothamsted, England, where undisturbed clay loam soil was enclosed in cemented tanks. The surface is kept free of all vegetation, so that measuring the drainage and

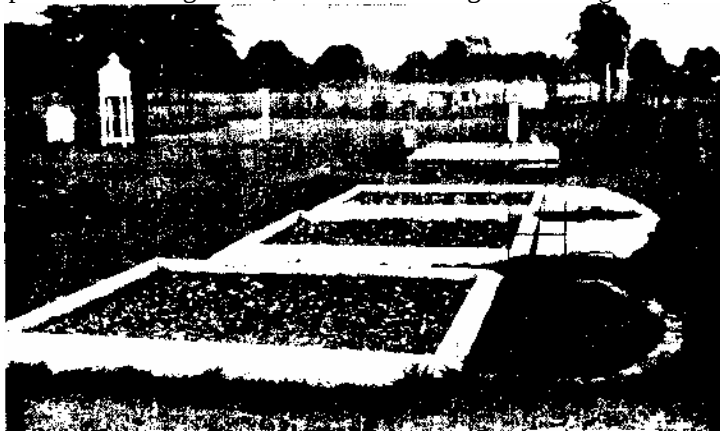


FIG. 15. Old lysimeters, at Rothamsted Experiment Station, Harpenden, England.

subtracting it from the rainfall gives the evaporation by difference.

The only drainage gauges in the West are at the Experiment Stations at Corvallis and Hermiston, Oregon; and Superintendent H. K. Dean has supplied the following statement regarding the interesting work there:

" Study of soil-moisture in the rather sandy soil of the Umatilla Experiment Farm led to the installation of eight lysimeters for the purpose of tracing, more closely than was possible under field conditions, the relation of the moisture to the soil. The lysimeters are 3.3 feet square and contain soil to a depth of 6 feet. The soil was taken from the field in 6-inch layers which were placed in their original order with their original density preserved as nearly as possible."

TABLE II. — RAINFALL, PERCOLATION, AND EVAPORATION
AT ROTHAMSTED, ENGLAND

AVERAGE FOR 34 YEARS 1871 TO 1904

(For 38 years' data see reference 11 at end of chapter)

Months	RAIN FAIL	PERCOLATION THROUGH SOIL			PERCENT OF TAIN FAIL PERCOLATING THROUGH SOIL		
		20 inches	40 inches	60 inches	20 inches	40 inches	60 inches
January	2.32	1.82	2.05				
February	1.97	1.42	1.57	1.48	72.2	80.0	75.2
March	1.83	0.87	1.02	0.95	47.6	55.6	52.0
April	1.89	0.50	0.57	0.53	26.5	30.0	28.0
May	2.11	0.49	0.55	0.50	23.2	26.1	23.6
June	2.36	0.63	0.65				
July							
August							
September							
October							
November							
December							

PERCOLATION FOR YEARS OP MAXIMUM AND MINIMUM RAINFALL							
Maximum (1903)	38.69	23.48	23.60	24.23	60.7	61.0	63.0
Minimum (1898)	20.49	7.32	7.90	7.69	35.7	38.5	37.6

" The five soil types used are fine, medium, and coarse sand, silt and silt-loam. The medium sand grows (1) no crop, (2) soy beans in the summer and vetch in the winter, both of these being turned into the soil, (3) alfalfa and (4) alfalfa manured annually. The fine sand, coarse sand, silt, and silt-loam soils grow alfalfa without fertilization.

" The percolation from the medium sand lysimeters has been greatest each year from that not growing a crop, decreasing in the order

mentioned from those growing soy beans and vetch, alfalfa, and alfalfa manured. The percolation from the lysimeters growing alfalfa has been lowest from the fine sand, greater from the medium sand, and greatest from the coarse sand. The silt and silt-loam soils have held all the water applied to them. The rate of percolation from the no-crop and from the soy bean and vetch lysimeters increases very rapidly, usually eight to



FIG. 16. Tile under each plot in Broadbalk field, Rothamsted, permit study of removal of substances carried in drainage water.

ten hours after irrigation, and has reached a maximum flow within an hour after the first increase. From the maximum the rate gradually decreases until the next irrigation. The increased percolation after irrigation from the fine, medium, and coarse sand growing alfalfa comes twenty to twenty-four hours after irrigation and does not reach as high a rate as from the no-crop and from the soy bean and vetch lysimeters. The results show that there is a tendency for the percentage of percolation to decrease as the soils are cropped."

TABLE III. — WATER APPLIED AND PERCOLATED FROM LYSIMETERS

Expressed in acre inches, six year average
Oregon Agricultural College and Branch Experiment Station,
Umatilla, Oregon

oil	Medium- Sand				Fine Sand	Coarse Sand	Silt	Silt-Loa
Crop	No Crop	Soy Bean and Vetch	Alfalfa		Alfalfa			
			With out Man-ure	With Man-ure				
Applied	57.9	58.4	57.9	57.9	60.0	60.0	59.7	61.0
Percolate	39.6	27.7	12.9	10.8	7.72	14.9	None	None

Manure and continuous cropping to alfalfa is gradually decreasing percolation year by year.

The quantity of water which percolated through lysimeters 4 feet deep at Corvallis, and the effect of manure (M) and lime (Ca) is given in Table IV. These treatments appear to have increased permeability.

TABLE TV. — TOTAL LEACHINGS (INCHES)

Year Treatmen t	1 None	2 M,Ca	3 M	4 Ca	5 Ca	6 M	7 M,Ca	8 None
1922-23	12.67	24.06	28.63	27.64				
1923-24..	6.90	12.61	17.10	14.54	12.03	16.50	16.36	13.34
1924-25..	20.55	39.18	37.87	37.05	34.02	36.08	35.40	33.62
1925-26..	12.85	17.42	17.56	16.21	16.00	15.70	17.12	16.20
1926-27..	31.47	38.96	38.66	37.36	35.97	36.16	36.15	36.06

3. *Evaporation* from the soil surface removes much of the rainfall, frequently, as with the Rothamsted Lysimeters, as much as 52 per cent. Evaporation from a free water surface may vary from 1/2 inch to 2 inches a week, and, taken for the year, may exceed the annual depth of precipitation.

4. *Transpiration*, through growth on the land, transfers enormous quantities of water from the soil into the atmosphere. The food of plants is taken up by the roots and carried, in dilute solution, to the leaves, where it is combined with the carbon dioxide of the air and forms the dry substance of the plant. The amount of water taken up in this way and given off again by the leaves averages several hundred pounds to each pound of dry matter produced. Transpiration usually eliminates several times as much water as evaporation. The two are generally measured together in determining the total water cost of dry matter, as given in Table V for different crops and regions of the world.

5. *Artificial Control of Soil-Water*. — In the practice of irrigation and dry-farming, we aim to conserve the supply of soil-water, while in drainage we decrease the amount. Three practical means of decreasing the soil-water supply are early ridged cultivation, growth of plants, and drainage.

Cultivation. — We can hasten evaporation by early spring cultivation of the soil, by increasing the air circulation, and leaving the soil with an uneven, ridged surface, which exposes a greater surface to evaporation. Cultivation may also increase the water capacity of the soil.

Growth of Plants. — Crops of any sort, weeds and cover-crops, will dry the soil by transpiration of water through the leaves. We take advantage of this in the early spring to take out the excess water, and again in the fall when the cover-crop is planted in the orchard to take up the moisture and check growth, so that buds will be prepared for winter.

Drainage. — Drainage consists essentially in the direct removal of gravitational water from the root zone of the soil, by providing free passages for its percolation and flow. This is the chief means of artificially decreasing the supply of soil-water. It is simply a means of aiding gravity in removing the excess supply.

The maximum outflow from the under drained areas in the Central States, where fairly good drainage is provided, varies from 1/4 to 3/8 inch an acre for each twenty-four hours. Systematic

measurements of outflow in western Oregon show that fairly good underdrainage would provide for the removal of 1/3 to 1/2 inch depth an acre each twenty-four hours.

TABLE V.—WATER COST OF DRY MATTER, DIFFERENT CROPS AND CLIMATES, EVAPO-TRANSPARATION RATIO

Crop	King, Wisconsin	Widtsoe, Utah	Wollny, Germany	Powers, Western Oregon	Irrigation Investigations Western Oregon
Wheat		1017			871
Barley	464	801	774	514	623
Oats	504	871	665		680
Corn	270	552	233	548	787x
Clover . . .	577			669	
Alfalfa		1,096		848	990
Peas . . .	447	1,118	4 6		852
Beets . . .		760		520	909
Kale . . .				937	
Carrots		710		500	
Beans				1 409	
Potatoes		1,375		694	502
Cabbage		4,413			
Onions		2,993			
Marsh Grass					1,349z 1
Timothy and Alfalfa					560

Average of plots giving best use. All representative determinations.

X Southern Oregon

Z Tanks

Movement of Water into Drains. — Drain-tiles 1 or 2 feet long are laid through the soil in one continuous line, with such a grade that all water which finds its way into them will be carried by gravity to the lower end of the line and there discharged. The water enters the opening at the ends, or " joints," as they are called. The ends of the tiles are placed close together to prevent soil from entering, but room is left for water to enter.

When the drain is surrounded by saturated soil, water flows

by gravity through the crevices in the ends of the tiles and passes off more or less rapidly according to the grade of the drain and the gradient of the water leading to the drain. Fresh soil-water takes the place of that removed by percolation, moving downward and laterally toward the drain, by the lines of least resistance. The lateral distance through which the drain will relieve the soil of water is governed by the depth of drain and the resistance which the soil particles offer to the flow of water among them.

This tile-drainage process does not leave the soil without moisture, but simply removes the excess, or free water, and makes more room for the storage of capillary or usable water. It does not remove the free water from points below the level of the drain. The free water which is removed may be due to seepage or directly to rainfall.

QUESTIONS

1. What different terms are used to refer to free water? Water-table?
2. What governs its movements?
3. To what extent can different crops tolerate free water?
4. How may the water-table be studied?
5. How may permanent observation wells be constructed?
6. What factors affect the topography of the water-table?
7. What conditions affect the prevalence and fluctuations of ground-water?
8. How does the effect of tile on the water-table in clay soil differ from its effect in sand?
9. What are the chief sources of rainfall and runoff data?
10. What are the different periods in the rainfall year?
11. What is meant by first-class and second-class drainage?
12. How does drainage increase the supply of usable soil-water?
13. In what different ways is excess rainfall disposed of?
14. Name the means of disposing of excess water artificially.
15. Explain how water enters tile.
16. How does water in the soil move to tile?
17. What can be done to aid the removal of excess water through a tile?
18. Give three methods of tracing seepage.

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CHAPTER V

TYPES OF DRAINS AND THEIR LOCATION

The different kinds of soil-drainage may be classified as follows:

1. Natural Drainage.
 - a. Through gravelly subsoil.
 - b Through surface runoff.
2. Artificial Drainage.
 - a. Through open drains.
 - b. Through under drains.

Both surface drains and underdrains have their fields of usefulness.

Open Drains or Surface Drains. — These are essential for outlet ditches for large areas. They remove water from the surface and, to some extent, from the subsoil as well. The amount which they remove from the subsoil depends upon their depth and fall, and the amount of water in the channel. Surface drains are of value:

1. Where the volume to be removed is large.
2. Where the water-table is near the surface, and the fall is so slight that it is impossible to place a drain below the surface.
3. Where the drainage is temporary.
4. As outlet ditches to receive tile discharge for large areas of flat land.

Disadvantages. — Open or surface drains have several disadvantages, as follows:

1. They are seldom of sufficient depth.
2. They are apt to have a low velocity, due to the uneven grades, rough bottom and sides.
3. They are expensive to maintain.

4. They waste much land.
5. They greatly interfere with cultural operations.
6. They may be subject to serious erosion.
7. The banks may become puddled, so that water from the surrounding land does not enter them readily.

Covered or Underdrains. — Underdrainage is usually the most complete and permanent form of drainage; underground drains make fields uniform with regard to moisture and facilitate farming operations. Many materials have been used for underdrains; but in recent years they have narrowed down to box-drains, cement drains, and clay tile drains, which are the commonest of all. Underdrainage will improve the soil where-ever there is not complete natural drainage. The extent to

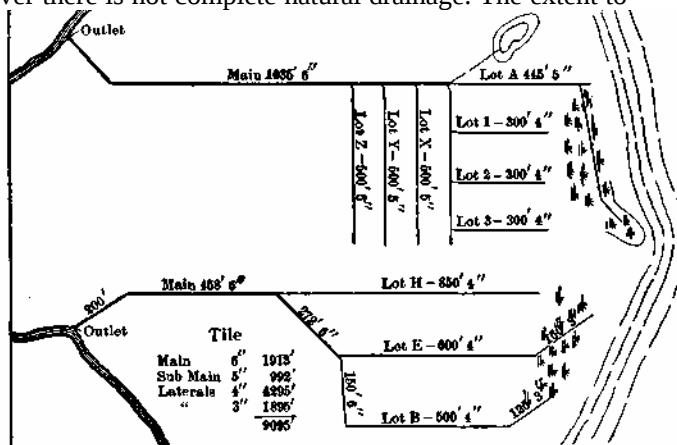


FIG. 17. The layout of a tile-drainage system.

which Underdrainage is justified depends on the value of the naturally drained surrounding upland and the net returns with and without drainage. More thorough drainage becomes desirable as the agriculture of a section becomes intensive and highly developed.

Relation of Surface Runs to Tile Systems. — To be most beneficial, drainage should be deep. It is practically impos-

sible to overdrain a soil. While the open furrows or field ditches are of value for temporary drains, there are several objections to them. Surface runs, or permanent, shallow, open ditches in the field, should be made to follow fences or direct lines as much as possible. They may be kept in grass and used to remove the flood-water in case of extremely heavy storms, after which underdrains will remove the excess water from the subsoil.

The Parts of a Drainage System may include the outlet, the head, a string of tile, a main or conducting drain and laterals or collecting drains, together with minor parts, which are discussed below.

The outlet for the lower end of the drain should be carefully located and have a free spillway. In laying out a drainage system

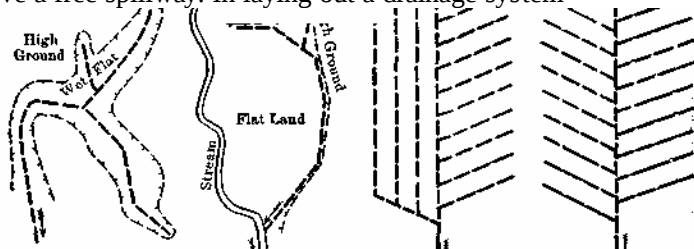


FIG.18. Types of tile-drainage systems.

the outlet should be planned first. It is useless to construct a system unless a fair outlet can be secured.

The head of a drain is the upstream end; this should not be confused with hydrostatic head.

A string of tile is a term used to designate a single line of tile that receives no branches. The *grade* is the finished tile-base at each station. *Gradient* is the slope of the tile-base and is expressed in fall per hundred feet.

A cutoff, or intercepting drain, first used by Elkington in England in 1764, will frequently protect a flat from seeps

above. It is a drain located so as to intercept seepage and cut the water off from lower land.

A *main or conducting drain* is a line of large tiles that carries the discharge from several laterals. It serves chiefly as a conducting drain and should be deeper than the laterals so that there may be free discharge and the larger tile may be protected from breakage.

Double mains are used where seeps appear on both sides of a broad flat, also where stream separates an open flat into two parts.

Sub-main is the term used for a smaller main discharging into a large main.

Laterals, or collecting drains, are usually single lines of tiling. If a short spur discharges into a lateral it can conveniently be called a *sub-lateral*. Laterals are frequently arranged in parallel lines to form thorough systems. Laterals serve chiefly as collecting drains.

Lateral systems include natural or random systems, grouping systems, herring-bone systems, gridiron systems, and parallel systems.

Natural or random systems of drains follow the natural de-pressions in the land, and diverge like the frame of a tree.

The grouping system is similar to the natural system, except that a few short laterals may be provided in wet areas or ponds along the system. The natural and grouping systems are adapted to undulating land and to lands of only moderate value. Such systems may be used to give fairly thorough drainage for ordinary crops, where increase in yield from drainage will be sufficient to pay a good rate of interest on the investment.

The herring-bone system is used where the wet land lies in two planes, with the main drain passing down the center. The laterals enter from the side, at an angle to the main, and are arranged alternately.

The gridiron system usually contains two mains at angles to each other, with parallel laterals discharging into each main from a single side. Such a system is suitable where the wet area lies in planes not facing each other.

A *parallel system* of drains with a single main and long parallel laterals gives the least amount of double drainage. Long parallel laterals should be used in place of short ones, as there will be less expense for junctions. The parallel system of drainage is well adapted to flat land lying in one plane.

A drain system should be so designed that there will be long parallel lines with few junctions and but little double drainage.

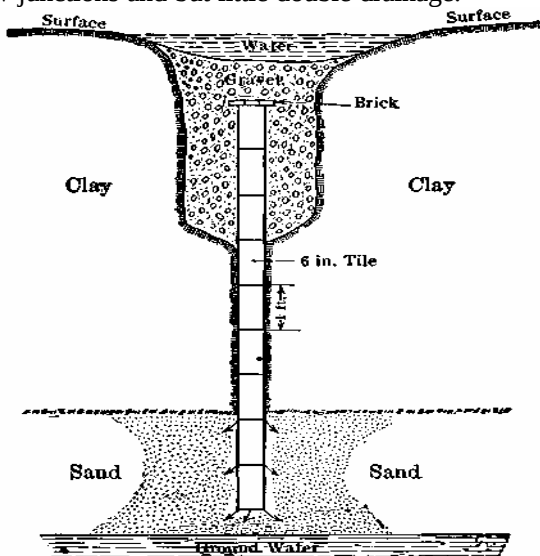


FIG. 19. Vertical drain.

Where convenient, the laterals should run parallel to the fence line and to the dead furrows, so that supplemental surface drainage can be provided.

Vertical drainage is practical only where there is wet land with a tight subsoil and a coarse layer or permanent crevices underneath, through which water will pass. A vertical drain can be made of small wells, below reach of the plow, lined with a column

of drain tiles surrounded with gravel and covered, making a permanent passageway down through the impervious layers.

Mole Drains. — The mole drain is sometimes made by using a subsoiler with a cannon-ball point which forms a hole through the subsoil in which water may drain away. Such drains are temporary, and a more permanent investment may usually be made by putting the same outlay into the most necessary tile



FIG.20. Constructing a temporary or so-called mole drain.

lines. The soil is often puddled by the ball point subsoiler and in dry weather the land may open shrinkage cracks along the line traversed by the plow shank, permitting loose particles to fall in from the surface and clog the drain. In some cases, tiles are drawn into the subsoil hole. (Fig. 40.)

The Location of Drains. — A carefully planned drain system may be installed in units, as time and means permit, and de-

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veloped so as to afford more thorough drainage as general economic conditions come to justify a higher state of improvement. *In locating drains the following principles should be observed:*

- (1). Lay the mains along the lines of natural drainage, where water collects on account of the slope of the surface and subsurface strata. This should always be done, except where a cutoff drain will effect an economy.
- (2). Lay the laterals along the lines of greatest slope. Otherwise, if the land is flat, the water may ooze out of the tile in the lower or sandier part of the course. Exceptions to this may at times prove economical or desirable in controlling silt or water-hammer.
- (3). Use long parallel laterals in place of short ones, where possible.
- (4). Make the lines straight or with gradual curves. They are easier to lay and to map, and offer less friction.
- (5). Bring all the wet land under the influence of the tiles.

How to Determine Where Drainage is Needed — Free water on the surface, or wet surface soil with the water-table near the surface at plowing time, is an indication of lack of natural drainage. It is desirable to see the land at the wettest season of the year. Flat land of fine texture in humid climates is likely to have imperfect drainage; and the topography and area of the tributary watershed, when considered with the amount and distribution of precipitation, will indicate the amount of flood-water to be contended with. Where wet land is in a clean cultivated state or free from vegetation, the light color of the surface soil in wet, low places will be apparent. Borings with the soil-auger will reveal the presence of ground-water, and a light gray or mottled subsoil will indicate an un-aerated, water-logged condition the greater part of the year. Gullying or erosion may also indicate need of drainage.

Vegetation common to wet farm lands includes sorrel, redtop, velvet-grass, buttercups, forget-me-nots, and docks. On muck lands, wire-grass, sedges, tussocks, mint, wild cabbage, cat-tail, and perhaps willows and spruce may occur; bulrushes may be found on medium or deep peat. On alkali land, salt-grass, foxtail, and greasewood are commonly found, while cat-tails and water-loving grasses may develop with water-logging in irrigated sections. The presence of tall rye-grass or buck-grass indicates slacked subsoil and free water within a few feet at certain seasons in the arid region, while rushes commonly mark the points of seepage in wet climates. Yellowing of crops and rank growth of fruit trees, with subsequent winter killing, are often related to poor drainage.

Location of Drains with the Auger and Level. — When designing a drainage system, it is best to begin at the outlet and determine the depth at which the drain can be placed and still have a free discharge. The level will be useful here. All leveling data should be referred to a permanent bench-mark. As the examination proceeds upstream test pits should be made at frequent intervals with a posthole-auger or soil-auger and the character of the subsoil observed with a view to placing the drain at the depth of the most free-working soil.

The occurrence of underground water should be noted, and any seepage water traced to its source, to determine whether it appears over or under any hard layers of soil. The drains can then be designed so as to intercept this water and convey it away as directly as possible. A few range poles or stakes should be set up at various points in the field through which it is desired to have the survey for the drains pass. Preliminary levels may be taken to decide on the best possible outlet and determine the lay of the land. A series of readings taken around or across the field in both directions will usually disclose the variations in a fairly flat piece of land. A map of a wet farm having irregular topography would be very desirable. Because drainage is a rather expensive improvement, and some soils, like the "white land," are rather slow to respond to it, the drains should be located, and the land handled after drainage, so as to loosen up

the soil and facilitate the entrance of water into the tile, thus making the enterprise thoroughly profitable and successful.

The use of catch-basins, the practice of allowing the subsoil to crumble before filling the trench, and the use of sods over the tile are all means of aiding the water to enter the tile.

The success of a drainage system depends largely upon its proper location. It is better to see the land both in the wet season and in the dry season before designing the drains. If only one examination can be made, the time of year that cultivation begins is the best time to locate land that is affected by surplus water in humid sections, or at the close of irrigation season in irrigated regions.

The farmer should study subsoil and ground-water conditions in wet areas, then view out a full system of drains by the aid of a level, if necessary. The system may be installed in units, most necessary parts first, but it is best to order tile in car lots. The farmer should make a study of drainage so that he can superintend and inspect his own work. He should sketch the tile lines installed and note results, extending the system as needed.

The community needing an outlet ditch should secure preliminary topographic and soil surveys to learn the costs, feasibility, and extent of the proposed outlet system. If feasible a petition for a drainage district should be prepared according to the state law and presented to the county court. The district officers are then elected and they employ a drainage engineer to secure plans and estimates. The county court appoints viewers or assessors, the district officers secure bids, let the contract, and superintend the construction.

QUESTIONS

1. Under what conditions may a surface run be used, and how is it designed?
2. Define outlet, head, cutoff, grade, gradient, collecting drain, conducting drain, sub-main.
3. Describe the natural or random system of tile and explain where it should be used.
4. Where is the herring-bone system suitable?
5. What are the advantages of the parallel system of drains?

6. Under what conditions should thorough systems of tiling be used?
7. Describe the vertical drain and explain where it may be employed.
8. State the principles to be observed in locating drains.
9. What soil conditions indicate need of drainage?
10. What kind of vegetation occurs on wet marsh lands? On wet farmland?
11. What are the first indications of water-logging? of alkali?
12. What points should be determined with the soil-auger in locating drains?
13. In designing drains, what data about the land should be obtained?
14. Explain the procedure for designing and estimating the drainage requirement of a wet field.
15. What can be done to facilitate entrance of water into tile?
16. What are mole drains and how are they made?

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CHAPTER VI

MATERIALS FOR COVERED DRAINS

A variety of methods and materials, including brush, poles and stones, have been used in the past for the construction of covered drains. Most of these were effective, but so crude that the modern cement and clay pipes have largely displaced them. In the earlier attempts at drainage, however, clay and cement tile were, of course, not available and the use of other materials was necessary.

The pole-drain has been used in regions where timber was plentiful and other material scarce. Three poles were placed in the trench, the third on top of the other two in such a way as to leave a small space for the water to flow between the three.

Box-Drains. — The box-drain is a type of drain still in use where timber is cheap and where the boxes can be kept moist throughout the

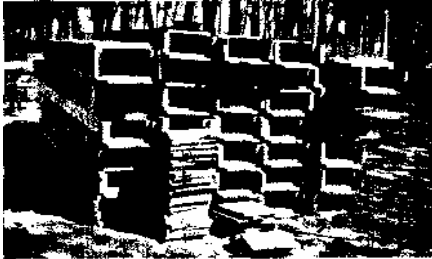


FIG. 21. Wooden box drains.

year. It is frequently used in draining alkali lands, where the action of the alkali would destroy cement tile. It is also used in peat lands, where the settlement of the peat would throw the short tiles out of line. The life of such a drain is reasonably long if it is always

wet; but if subjected to alternate wet and dry conditions the boxes rot out in three or four years. Such drains must be so constructed that their integrity of shape does not depend on nails, as nails rust away in a short time, whereupon the box, if not correctly constructed, will collapse. Neither

open-bottom boxes nor triangular boxes should be used for drains. Both of these types have a tendency to choke.

The most modern material for underdrains is tile. It may be made either of concrete' or of clay.

Concrete Tile. — During the last twenty-five years, concrete tiles have been used more or less throughout the United States. They have competed successfully with clay tile in sections where there was a scarcity of suitable clay or a lack of transportation facilities. They are now being used in every section where drain-tiles are required.

In order to prevent destruction by frost, the tiles should be as dense, or water-tight, as possible. The concrete should therefore be mixed in accordance with the tenets of the "water cement ratio theory. The proportions as established by that theory are usually about 1 part of cement to 3 parts of coarse sand well mixed and avoiding an excess of water. There is a tendency among farmers to construct their own tiles, using leaner mixtures; but this invariably results in failures, which have contributed much to the unpopularity of this kind of tile. The lean mixtures cannot be recommended, and concrete tile construction should be left to experienced makers. If proper precautions are observed in the making, concrete tiles will prove satisfactory everywhere except in the presence of acids or certain alkali salts. In irrigated regions the character of the alkali and its effect on concrete tile should be determined before using such tile.

It is rather difficult to determine by inspection that a concrete tile is faulty. When the cement is good and the materials well mixed and allowed to set properly, the tile is likely to be durable. The following rules may aid in detecting defective concrete tile.

1. The more cement used in making tiles the lighter in color they will tend to be. A dark-colored concrete tile, or one which seems light in weight for its size, should be looked on with suspicion unless dark sand has been included.
2. Concrete tiles may fail under slightly less load than clay tiles. To test the strength of a 5 to 8 inch cement tile, jump

on it as heavily as possible. If you cannot break it, you are fairly safe in using it. A small concrete tile should hold up a load of 1000 pounds to each foot of length, without support on the sides.

3. Try crumbling off the edges or corners, with the fingers. If it crumbles easily the tile should be re-jested as being made of poor materials or lean mixture.
4. Concrete tile will not give as sharp a ring, when rapped with a piece of steel, as clay tile; but once one is accustomed to the sound it is easy to detect defective concrete tile by this method.
5. Weigh a tile; then soak it twenty-four hours under water. Weigh again, and if it has absorbed more than 9 per cent, by weight, of water it should be rejected. Good concrete tile will absorb between 3 and 9 per cent water.

Effect of Alkali on Concrete Tile. — Laboratory experiments show that alkali will disintegrate concrete in two ways. First, if the concrete is somewhat porous, and it is constantly supplied with a salt solution which is permitted to crystallize in the pores, the expansion of the salt crystals during the process of crystallization will exert enough mechanical force to crack the concrete. Second, if hydrated cement is brought into intimate contact with certain sulphate or chloride solutions, the uncarbonated lime of the cement is subjected to rapid solution, with a resulting decomposition of the cement.

The Bureau of Standards, in cooperation with the Bureau of Reclamation and the Portland Cement Association, has for the past few years been investigating the effect of alkali on concrete drain tile in the arid sections of the West. The investigations covered 9000 different tiles of twenty different varieties, and involved their shipment to various government projects in the alkali regions of the West, and to fresh water projects in Minnesota and Missouri.

These experiments show that the presence of alkali in the form of sulphate of sodium and magnesium in any considerable amounts, has a disintegrating effect on concrete, greatly reducing its strength and causing it to crumble. This is particularly true of mixtures leaner than 1 part cement to 3 parts sand, while mixtures richer than 1 to 3 are but slightly affected. Common salt (sodium chloride) and sodium carbonate do not seriously injure concrete tile.

Concrete tile that is to be used in alkali soil should be made of selected and tested materials, so proportioned as to produce a very dense concrete. As small an amount of mixing water should be used as will allow the proper placing of materials. Unless such precautions are taken there will be insufficient resistance to alkali action. The Bureau of Standards has drawn the following conclusions regarding the use of concrete tile in soils or waters containing more than 0.1 per cent alkali.

1. The use of concrete tile in alkali soils is experimental.
2. Tiles which are porous because of lean mixtures or relatively dry consistencies are subject to disintegration.
3. Some dense tiles are, under certain conditions, subject to surface disintegration.
4. Disintegration is manifested by physical disruption, caused by expansion resulting from crystallization of salts in the pores, and also by softening, resulting from chemical action of the solution with the constituents of the cement.
5. Indications are that the greater the quantities of sulphates and magnesium present and the greater the total concentration of salts, the greater will be the disintegration.
6. Rich tiles, as commonly made, are subject to disintegration when exposed to soils or water containing 0.1 per cent or more of alkali salts.
7. Hand-tamped tiles are not equal in quality to machinemade concrete tiles and do not resist alkali as well.
8. Steam-cured tiles show no greater resistance to alkali

action than tiles that are cured by systematic sprinkling.

9. Tiles made of sand-cement have less alkali resisting powers than those made of Portland cement.
10. Neither tar-coating nor cement grout is effective in preventing the absorption of alkali salts from the soil.
11. The introduction of ferrous sulphate into the cement as a waterproofing agent is found to be of no advantage.

Effect of Acid Peat on Concrete Tile. — Studies by G. R. B. Elliott indicate that free alkali is present in concrete tile and reacts with the carbonic and other acids in water from peat soil, yielding calcium bicarbonate and increasing the porosity of tile. Low porosity and the presence of more subsoil retards but does not prevent the process of disintegration in wet peat.

A solubility effect is probable, though it is conceivable that a base exchange or exchange of calcium ion for the acid hydrogen ion may occur. Finer grinding and complete hydration on "setting," washing of the "aggregate" and oil or other coating in the tile may offer means of improvement. Concrete tile after six years' use in University of Wisconsin marsh showed signs of failure. Decomposition occurs mainly at the ends and outside.

Failures and Requirements. — Many costly mistakes have been made in the development of concrete tiles. These occasional failures are invariably due to one of three causes: (1) poor materials, (2) too lean a mixture, (3) poor workmanship in mixing and tamping the concrete.

A mixture of 1 part good Portland cement to 3 parts good clean sand, well mixed and of a workable consistency, produces a good tile. The walls of the tile should be thicker than those of clay tile. In curing, care should be taken not to permit the material to dry out too fast. The green tile should be kept moist for several days by sprinkling, to prevent cracking.

Clay Tiles. — There are three classes of clay tiles: (1) Farm drain tile, (2) Standard drain tile, (3) Extra quality drain tile.

The first is made of surface clay burned at low temperature. The second is usually shale but may contain a large percentage of surface clay. The third is made of shale vitrified at high temperature. The general quality essential to its manufacture is that the clay be sufficiently plastic when wet to be forced through a die and molded into a cylinder without serious cracking or checking. Many kinds of clay possess these characteristics, and it is seldom that such clays do not make good drain tiles. Surface clays are sometimes added to the

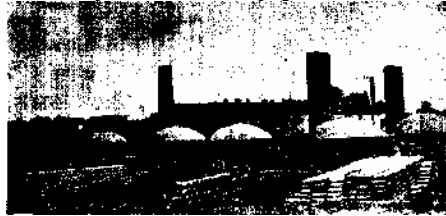


FIG. 22. Shale tile plant, Sheffield, Illinois

deeper clays by turning to control shrinkage, color, and density of the tile. Deeper clays, such as may be found at a depth of 10 to 12 feet, may not be satisfactory when used alone. They are apt to shrink and warp or to develop shelly structure (caused by the auger of



FIG. 23. Shale pit supplying plant shown in Fig. 22.

shrinks in burning, the length and thickness of the walls, and the diameter may vary somewhat with the degree of burning. The over-burned tiles will be smaller. The well-burned pieces are usually 1 foot long. For smaller tiles, except in the case of the hardest-burned, there will be a slight over-

the clay-machine) which is called "auger" or " laminated " structure. This defect is corrected by the addition of sand or sand-bearing surface clay. Good tiles are practically cylindrical and give a clear, sharp ring when struck with a piece of metal. Since the clay

run which will about compensate for breakage in transportation.

Salt glazed tiles are made by treating the fire with salt, thus causing chlorine fumes which form a flux with the silica, giving the tile a smooth surface.

Vitrified tiles are usually made of ground shale or high-grade shale clay mixed with common clay. These stand a higher heat and will fuse and form a hard mass of greater strength and less absorption qualities than the common clay tiles. Over-burning this ware makes it weak and brittle. Vitrified tiles are usually dark brown in color. They are always good; and, if the price is the same, they are preferable to ordinary clay



FIG. 24. Styles and forms of shale tile.

tiles. If hard-burned, first-quality common clay tile can be obtained, however, they are just as good for farm drainage purposes. Vitrified pipes are especially useful at the outlet when exposed to frost. Clay tiles, when exposed to the air in freezing and thawing weather, are likely to disintegrate; but when buried below the frost line they are not so affected and are permanent.

Standards and Tests. — The quality of vitrified tiles varies greatly. Tests show that over-burning will make the material brittle and impair its strength. Care should be taken to select tiles of medium burn deep trenches, as these tiles are tougher and stronger than the brittle, hard-burned tiles. Tile-layers should be instructed to throw out all tiles that are soft, cracked, or ill-shaped. Medium tiles are usually straight. All tiles warp more or less in burning, but badly warped pieces should be thrown out.

Second-class sewer-pipes may frequently be obtained from

the manufacturers at prices which warrant their use for drain-tiles. If the worst pieces are rejected, they make excellent tiles in preserving the alignment, especially if the joints are cemented in the worst places.

Inspection of Clay Tiles. — All clay drain-tiles should be thoroughly inspected before laying. They should be hard-burned, true to shape, with full rated dimensions both as to diameter and length, and should give a clear metallic ring when struck with a piece of steel. A cracked tile can easily be detected by the absence of this ring. One crack, not to exceed 20 per cent of the length of the tile, may be allowed but no more.

Hard-burned tiles are usually the best. Hardness or density is indicated by the cherry-red color, which is generally preferred, since it indicates thorough burning and absence of impurities in the clay. The porosity of the tiles may be tested by the water-absorption test, which is made by weighing the tiles dry, soaking them in water for twenty-four hours, and weighing them again on removal from the water. The grade of tiles can be determined as follows:

Soft tile absorbs 10 per cent by weight in twenty-four hours Hard-burned tile "8"

The thickness of the tiles is also important, from the standpoint of strength and for making good joints.

The weight of a 4-inch tile should not be less than 6 pounds, that of a 5-inch tile, 8 pounds, and that of a 6-inch tile, 11 pounds, for each foot of length. In the larger sizes, if the difference

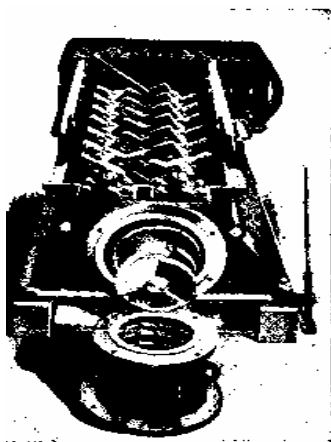


FIG. 25. This machine mixes the clay and forces it through a die onto the table shown in Fig. 26.

between the greatest and the smallest diameters exceeds the thickness of the shell, the pieces should be thrown out.

Other Simple Tests for Clay Tiles. — *Breaking Tests:* Clay tiles should have a bearing strength according to the following table, taken from the Yearbook of the American Society for Testing Materials:

A simple field testing apparatus can be arranged as follows for testing ordinary farm tile: Take a pole 12 feet long and fasten one end, with a chain or bolt, to a post or sap-ling. Place the tile to be tested

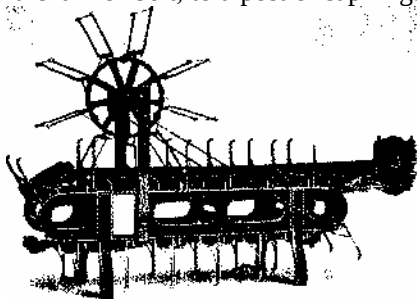


FIG. 26. Tile cutting wheel and table.

between two boxes of sand, one above the other, the inside dimensions of the boxes being an inch or two greater than the outside dimensions of the tile. Place the center of the boxes 11/2 feet from the fixed end of the lever if the apparatus is to be used by a 180-pound man, or 2 feet for a 200-pound man. Bring the throw the man's entire weight on the outer end of the lever, 10 feet from the fixed end. This will put a pressure of 1000 pounds on the tile. If the strength of the tile is equal to this test it is sufficient for practical purposes. Several tiles should be tried before a decision is reached. If there is a large percentage of failures, the lot should be rejected.

The American Society for Testing Materials gives the following specifications for arranging the sand boxes for tile tests: Where sand bearings are used, each specimen shall be accurately marked (around the circumference) in quarters, with pencil or crayon, prior to the test. Specimens shall be bedded above and below in the sand for 1/4 the circumference of the pipe, measured on the middle line of the shell. The depth of the bedding at the thinnest points above and below the pipe

shall be equal to 1/4 the diameter of the pipe, measured between the middle lines of the pipe walls.

TABLE VI. — STANDARD DRAIN-TILE

Internal Diameter of tile in.	Minimum Average Ordinary Supporting Strength, pounds per linear foot	MAXIMUM AVERAGE ABSORPTION BY STANDARD BOILING TEST, PER CENT*		
		Shale and Fire-Clay tile	Surface-Clay Tile	Concrete tile
4	1200	9	13	11
6	1200	9	13	11
8	1200	9	13	11
10	1200	9	13	11
12	1200	9	13	11
14	1200	9	13	11
16	1300	9	13	11
18	1400	9	13	11
20	1500	9	13	11
22	1600	9	13	11
24	1700	9	13	11
26	1800	9	13	11
28	1900	9	13	11
30	2000	9	13	11
32	2100	9	13	11
34	2200	9	13	11
36	2300	9	13	11
38	2400	9	13	11
40	2500	9	13	11
42	2600	9	13	11

*According to E.R. Lones concrete is inadvisable for peat soil if absorption is over 7 per cent.

The sand used shall be clean sand which shall pass a No. 4 screen. The top bearing-frame shall not be allowed to come in contact with the pipe or with the test-load. The upper surface of the sand in the top bearing shall be carefully struck level with a straight-edge and shall be carefully covered with a heavy rigid top bearing plate, with lower surface a true plane made of heavy timbers or other rigid material capable of uniformly distributing the test load without appreciable bending.

The frames should be dressed on all interior surfaces, and no

frame should come into contact with the specimen during the test. Strips of cloth may be used on the lower edge of the upper frame to prevent loss of the sand during the test. The load must be applied at the exact center of the upper bearing, in such a way as to allow free movement of the bearing in either direction. This may be accomplished with two rollers at right angles, one on top of the other. The Minnesota Agricultural Experiment Station has recently reported comparative tests with a new test bearing. Results with this Minnesota bearing when multiplied by four-thirds compare well with results obtained by use of the sand bearing. According to Minnesota results, sand should be used which contains 5 per cent moisture, and should be loosened by spading before each test.

Absorption Test. — Weigh a tile, then immerse it in water for twenty-four hours and weigh it again. If the gain in weight exceeds 9 per cent, a soft, porous tile is indicated. Such tile should not be used, especially above the frost line.

Durability of Tile. — In any place except in alkali soils containing sulphates of sodium and magnesium, there is little choice between concrete and clay tile. With the above exception, one is as durable as the other. The small-sized clay tiles usually can be made to better advantage in competition with concrete than can the large sizes.

QUESTIONS

1. Of what materials were the earliest drains constructed? What may be said of their durability?
2. Describe the brush, stone and pole -drains.
3. What is the objection to the use of box-drains?
4. Why are they constructed without nails?
5. Why should concrete tiles be made of very dense mixture?
6. What does a light color in concrete tiles indicate?
7. How does the breaking-strength of concrete tile compare with that of clay tile? Describe a good practical field test for breaking-strength.
8. How much water may a good concrete tile absorb in the twenty-four hour soaking test?
9. What alkalies are most apt to disintegrate concrete tile?
10. How is the disintegration accomplished by these alkalies?

11. What kind of concrete mixture would you use to lessen such dis integration?
12. What is the effect of acid peat on concrete tile?
13. What was the shape of the first clay tile?
14. Why was the shape abandoned?
15. What are the essential qualities of good tile-clay?
16. How may laminated structure of clay tile be avoided?
17. What are the vitrified tiles? Of what are they made?
18. What can you say of the uniformity of quality in clay tiles?
19. What are the qualities of clay tiles upon which the inspector must insist?
20. Describe the simpler tests applied to determine the quality of clay tiles.
21. Is it conceivable that exchange of bases would aid decomposition of concrete in peat or alkali soils?

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CHAPTER VII

DEPTH AND FREQUENCY OF TILES

The depth, frequency, and size of tiles are subjects which are closely related and are among the largest questions to be decided in tile-drainage. These factors can be definitely determined only after consideration of the character of soil and subsoil, the amounts and distribution of rainfall, topography of the surface and the amount of runoff, the crops to be grown, prevalence of underground water, the grade obtainable, and area to be drained. The tile system should always be arranged with reference to these considerations.

Depth for drains depends upon the kind of crop to be raised and the nature of the soil. King states that the depth must be

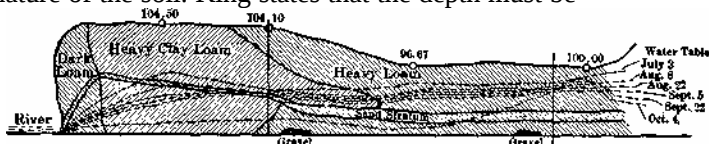


FIG. 27. Profile of alkali soil and water-tables.

such that water can get to the tiles before it seriously injures the crop. If water is kept moving and contains some air, the crops are less liable to injury. Some crops are more tolerant of an excess of water than others. The drains should be in the water to be removed and below the bulk of the roots. Deeper drains will in general be necessary in orchards and with deep-rooting crops.

The soil also affects the depth for drains. In porous soils, drains can be placed at a good depth, perhaps $3\frac{1}{2}$ or 4 feet. This permits deeper drainage, and the draining of a greater area by a single line of tiles. In sand, it is not generally desirable to

lower the water-table as far as plant roots extend. In some of our peat soils, sub-irrigation takes place, moisture being drawn upward by capillarity and distributed through the soil at an elevation of 30 to 36 inches above the water-table. In porous soils, drains attain their full efficiency almost at once; but in dense clay the efficiency increases as the soil becomes granulated and the drain system becomes effective. Some silt is washed out through the tiles, and after a few years tiny streamlets are formed leading to the joints in the tiles. In clay, in order to dispose of the water promptly, the drains must be fairly near the surface and used chiefly to dispose of water in the surface layer. Tiles should be placed on the boundary between sand and clay, if there is a change in soil texture at any reasonable depth. This allows water to move to the tiles through the sand, along the line of least resistance. The proper depths for different soil types and conditions are further discussed below.

Frequency of Drains. — The distance between drains is closely related to the depth and is affected by about the same conditions. The relation of depth to frequency in a porous soil is fairly definite. For example, twenty-four hours after a sandy soil has been saturated by rain, a study of the water-table extending back at right angles to the tile line will show it to have an even grade toward the tile. At a distance of 50 feet back, the elevation of the water may be 1 foot above the elevation of the tile. Under this condition, with porous soils, tiles placed 1 foot deeper should lower the water-table 1 foot farther from the soil surface at the 50-foot point, and should pull the water-table down to an elevation of 2 feet above the level of the tile, at a distance of 100 feet back. In a clay soil this grade would run in an arc instead of a straight line; at a distance of perhaps 25 feet from the tile, the water-table might be 2 feet above the level of the water in the tile, twenty-four hours after a heavy rainfall. The soil texture, therefore, affects the distance which may be left between drains. Fine-grained or heavy soil offers a great deal of friction or resistance to the movement of water, and such soils require frequent laterals for thorough drainage.

The rainfall and the time within which it is necessary to re-move it also affect the allowable distance between drains; and, if water must be removed in a short time from the heavy soil, drains must necessarily be placed close together and near the surface.

Surface of Ground

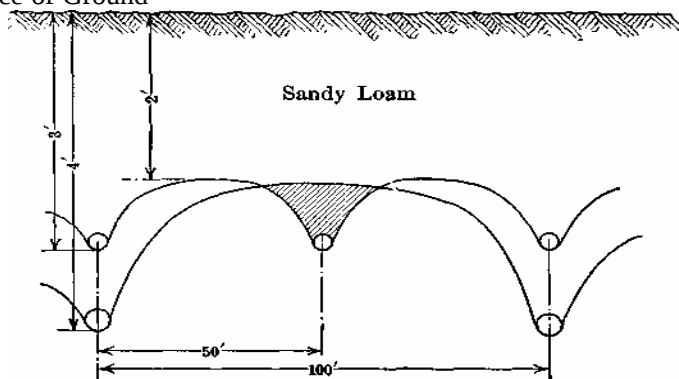
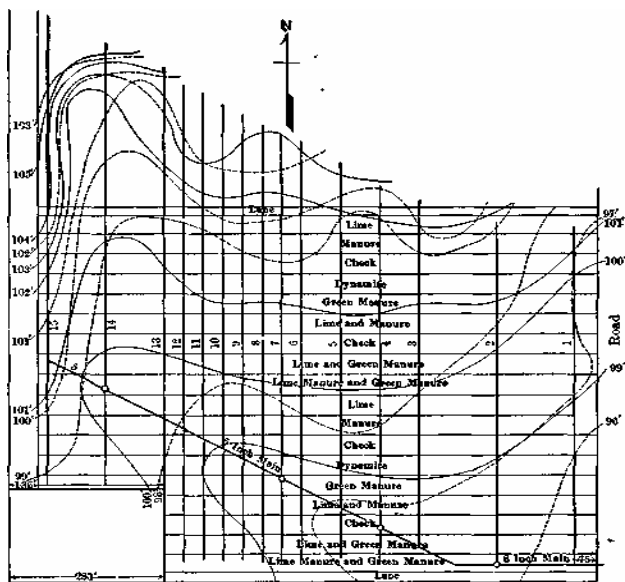


FIG. 28. — Influence of spacing and depth of tile drains upon ground-water.

Experiments Relating to Depth for Drains. — For several years hundreds of miniature wells have been maintained during the wet season in typical drained and undrained "white land" areas, to show the fluctuations in the water-table and the effect of the soil layers and tile-lines upon the position of the ground-water. In typical "white land" there is usually a heavy clay sub-surface, beginning at a depth of 12 or 15 inches and extending to a depth of 30 or 36 inches below the surface of the ground. The soil then changes to a yellowish, silty clay loam, which is usually somewhat mottled, showing brown spots where the soil is set with larger amounts of iron and clay. From these studies, it is found that in the flat areas of "white land" tile placed at a depth of about 33 inches will generally be below the blue clay sub-surface and in the most porous layer to be encountered. Placed at this depth, *tile-drains have lowered the water-table sufficiently*

In two drainage systems on the Experiment Station farm at Corvallis, where the laterals average about 3 feet in depth, as much as $\frac{1}{2}$ inch of rainfall an acre is frequently discharged in



twenty-four hours. One of these drainage systems has been in operation for twenty-five years, and the other for two years. *The structure of this land shows gradual improvement since the installation of drainage.* Observations of the discharge from other drainage systems on College land, where the tile laterals are 40 to 42 inches in depth, show that these drains do not discharge

charge more than $\frac{1}{4}$ to $\frac{1}{3}$ inch an acre in twenty-four hours, under the same soil and weather conditions that cause a $\frac{1}{2}$ -inch runoff from the

shallower drains. A drainage system capable of removing $\frac{1}{2}$ inch to the acre in twenty-four hours is regarded as fairly good for Willamette Valley conditions.

A series of lateral drains was installed in 1908 on a piece of "white land" near Albany, Oregon, by the U. S. Office of Drainage Investigations, the laterals being placed the same distance apart, which was 60 feet. The depth varied from $2\frac{1}{2}$ to $4\frac{1}{2}$ feet.

Results of Experiments Relating to Depth. — Frequent observations of the water-table and the discharge from these drains show that no advantage has been secured from drains deeper than the average in this type of soil. The present owner of this land states that he has been unable to discover any difference in crop yields or conditions in favor of the deeper drains. A study of water-table conditions in the vicinity of these drains indicates that, for at least two weeks after heavy precipitation, drains laid $4\frac{1}{2}$ feet deep are less effective with this soil than those laid at a depth of 33 to 36 inches. This is probably because the so-called "white land" has a rather impervious sub-surface layer, and the most friable stratum that can be found underneath occurs at depths of about 33 inches below the surface. The water that falls on such land and accumulates there comes from heavy rainfall rather than seepage, and does not find its way into the deep drains as readily as into those of an average depth.

A new experimental drainage system, having a deep outlet near at hand, has been installed on the 3-acre piece of "white land" on the Experiment Station farm near Corvallis, Oregon; and a further study is being made here of the effect of drains at different depths. The soil has been found to be fairly uniform. Manholes have been constructed, so that the runoff from laterals of different depths can be measured. In one section of this experiment the relative values of straw and gravel, placed over the tile-lines to aid percolation, are being studied.

Studies of this tract have been made by the writer for several years, and it has been found that the water-table is affected 25 to 30 feet back from the tile, twenty-four hours after rains have

caused saturation or rise of the water-table to the surface. Where the laterals are a greater distance apart, water frequently stands in the dead furrows for several days at a time. It appears that $3\frac{1}{2}$ feet is an effective depth here.

The Iowa Engineering Experiment Station, after studies of the operation of representative tile systems in that state, recommends that tile be placed, in Iowa, at a depth of about 4 feet, unless the subsoil is very impervious, when a $3\frac{1}{2}$ -foot depth may possibly be used. The land so drained can usually be passed over dry-shod.

Lynde studied depth and spacing for tile-lines in North Carolina under the conditions of 51 inches annual rainfall, 17 inches falling in summer. The action of tile in lowering the water-table was found to be irregular and to vary with texture of soil. Soil texture was reported to be the controlling factor in the efficiency of tiling.

Jones investigated the effect of depth and distance on tile drains in the Huston clay of the prairie section of Alabama by means of water-table studies and outflow measurements. It was concluded that $3\frac{1}{2}$ feet was an effective depth and that 75 feet was a suitable distance between laterals in Huston clay. The gray phase of this soil type was found to need tile-lines placed 60 feet apart and 3 feet deep. A capacity of $\frac{3}{8}$ to $\frac{1}{2}$ -inch depth an acre a day was adequate, the larger capacity being needed when surface inlets were used.

Experiments on Heavy Soil. — A field of "white land" on the Experiment Station at Corvallis was provided in 1914 with an experimental drainage system in which the laterals were installed at a depth of about 3 feet, at distances of 25, 50, 75, and 100 feet apart. See Fig. 29. The surface and water-table topography, as well as the arrangement of tile-drains and the sub-sequent surface treatments are shown in the accompanying figure.

Experiments Relating to Distance Between Drains. — For several seasons, wells have been maintained at regular intervals over this area during the early spring season. Before drainage, the water-table was within a few inches of the surface during

March and April, while, in the year following drainage, the water-table in the more thoroughly drained part of the field averaged about $2\frac{1}{2}$ feet below the surface at the corresponding season.

During recent wet seasons the rate of discharge from guarded laterals representing each spacing studied has been measured at regular intervals in wet weather.

These laterals are each 500 feet long. A 25-foot lateral drains approximately $\frac{1}{3}$ acre, while the 50-foot laterals drain $\frac{2}{3}$ acre each, and so on. Table VII gives the rate of discharge for each spacing, expressed in acre-inches runoff an acre in twenty-four hours, and the crop yields to the acre.

Winter barley on undrained land, under similar conditions, yielded 16 or 18 bushels to the acre, whereas marked increases are shown for this crop after drainage. Laterals



FIG. 30. Tiling at right is being studied in comparison with surface drains at left of outlet ditch. Reclaimed sea-bed, Zuider Zee Experiment Station, Holland.

removed the excess water more promptly than was anticipated, considering the heavy nature of the soil. Little outflow from laterals occurred preceding the maximum runoff, on March 26. Rainfall for March 25 was 1.28 inches; for March 26, the maximum discharge was observed at the close of the wettest day of the year, to be 1.89 inches. Dry weather followed and laterals had nearly ceased discharging by March 28.

These experiments are being continued, and equipment is to be secured that will enable the investigators to keep more nearly continuous records of rainfall and runoff. Winter barley grown on this field in 1924-1925 produced an average yield of over 50 bushels an acre.

TABLE VII.— DISCHARGE FROM LATERALS PLACED
DIFFERENT DISTANCES APART

Distance between laterals (feet)	Maxi- mum disch acre-ins, an acre per 24 hrs	Mea n dis ch arge acre- ins, an	Mean Daily rain previou s two days (ins.)	Daily outflow (per- centage)	No. Tiles to the acre	Mean acre- ins, dis- charge per 1000' tiles 24	Yield barley per acre 1915 (bushels)
25	1.20	.48	0.60	80	1742	.96	33.73
50	1.35	.55	0.60	92	872	1.10	29.29
75	.80	.33	0.60	55	586	.66	27.90
100	.90	.32	0.60	53	436	.64	20.35

The effect upon the water-table of these tile lines has been studied for a decade. Tile wells surrounded with coarse sand are used for these observations.

The results so far obtained indicate that the 25-foot spacing handles excess water most quickly. The 50-foot spacing gives the highest efficiency for each 100 feet of tile employed, while the 100-foot spacing continues to drain after the laterals have ceased to discharge into it at the manholes where measurements are taken. It is believed that, in this soil, deeper drains will act more slowly, but will continue to drain for longer periods of time than will drains of an average depth. The soil is dry enough for tillage and seeding operations, however, a few days after the water-table has been lowered to an average depth of 30 inches below the surface, a reduction which takes place promptly with laterals placed 75 feet apart.

Soil-moisture determinations made on drained and undrained "white land" show as much as 4 per cent more moisture in drained land in dry weather.

Some time ago, a list of questions was sent out to farmers who had installed drainage systems. Replies from some fifty farmers covering their experience with approximately 100 miles of tile in the Willamette Valley, show that the average depth of mains is approximately 4 feet. The average depth recommended in the replies is 3 feet. The laterals range from 4 to 10 rods apart, the average distance reported being 83 feet. An average distance of 4 rods between laterals is recommended; though 50 feet was a common reply. Practically all of these tile systems were declared successful by the landowners.

The Iowa Engineering Experiment Station, after thorough investigation, reports that laterals spaced 50 feet to 100 feet apart, in ordinary soils of that state, will give adequate drainage for field crops. It is not considered profitable to place them more than 75 feet apart. A distance of 33 to 50 feet is recommended for heavy soils or intensive crops, while for unusually open soils a distance of 150 feet is regarded as sufficient.

Laterals for Other Loam Soils. — Loam usually requires a random or natural system of drains, larger tiles being placed at the natural depressions in the land. These laterals should be of good capacity and good depth, perhaps $3\frac{1}{2}$ feet for smaller sizes and 4 feet for the 8 to 12 inch sizes.

Generally the soil will be a little heavy in these draws, but the drains can be placed deeper if occasional catch-basins are installed. Drains placed in natural depressions should be deep enough to receive the discharge of any laterals that may need to be installed later. Flat, wet areas of brown loam require thorough drainage, and can be drained fairly well with tile-lines six rods apart. Gray-brown silt loam or "near-white-land," in this valley, requires more thorough drainage; under average conditions tiles $3\frac{1}{2}$ feet deep every 5 rods should provide good drainage for this rather wet land.

Heavy clay or "black sticky" soil can be greatly improved by the use of protecting drains to collect the water before it gets into the sticky area. It is very doubtful whether it would pay at present to provide the thorough, expensive underdrainage necessary for the highest development of this land. Much soil of this type is underlain with a rather porous layer of sand at a

depth of about 4 feet, and, by the time the surface water is disposed of, no water-table is to be found in the subsoil and the land is ready for cultivation, which must be performed while the ground is still rather damp.

Field drains for red hill soils are usually for the purpose of controlling erosion or to collect seepage water from springy areas. If the land to be drained is used for an orchard, tile-lines should be located between the three rows, following spaces diagonally, if necessary, and avoiding the trees as much as possible. Study of the subsoil conditions will usually reveal hard layers of shale or clay which are responsible for crowding the water out to the surface. Sometimes intercepting or collecting drains, with the aid of relief wells, will be effective in drying up seepage from these hill lands. The cutoff for protecting drains should usually pass along the slope, with a fall of at least 3 to 6 inches each 100 feet, and just through the upper edge of the springy area. Short laterals may need to be added a year or two later to complete the drainage.

Laterals for Peat and Muck Soils. — Raw peat is subjected to considerable shrinkage upon drainage, and 4 feet is regarded as a minimum depth for laterals. Deep, raw, peat soils will be greatly benefited by laterals placed 500 or even 1000 feet apart. Where considerable silt is present, so that the soil is a rather dense muck, more thorough drainage is required, and the drains should then be only 3 or 4 feet deep.

Peaty Silt Loam or Tide-Land. — Near Astoria, at the Astoria Branch Experiment Station, an experimental drainage system has been installed on diked tide-land, and so arranged that guarded laterals are 50, 75 and 100 feet apart, and from 3 to 5 feet deep. The depth is greater where the laterals are 100 feet apart. Outflow, water-table, and yield data for the first season indicate that in tide-lands, where a sufficient depth of outlet can be secured, field laterals may be placed 4 feet deep and 75 or 80 feet apart.

Shallow peat that is underlain with black clay loam, or blue silty clay loam, is less attractive and less susceptible to drainage improvement. Peat, with some organic material, and especially

with some sand deposited by water action, is readily drained and is apt to supply more evenly balanced plant-food. In some of the " beaver-dam " areas, where the water-table disappears naturally late in the season, permitting thorough maturing of onions and other crops, the growers prefer to have laterals only 30 or 36 inches deep, in order that the crop may sub-irrigate early in the season. Raw peat may not " sub " over 18 inches, while silty peat may sub-irrigate 30 inches to 36 inches above the water-table. Where sub-irrigation is desired it would probably be better to have the laterals at least 4 feet deep, and to provide check-gates in the outlet drains, to delay the removal of the water-table beyond the reach of crop roots until later in the growing season. Grass will flourish with a water-table 2 feet from the surface, while for grain a depth of 3 or 4 feet, and for clover and other legumes a depth of 4 or 5 feet would be better. A large amount of valuable marsh land awaits reclamation on the Pacific and Atlantic coasts, and the subject warrants special study.

Laterals for Irrigated or Alkali Lands. — In draining irrigated lands, the drains must be placed at a great depth. Frequently a drain intended to intercept seepage is located in some deep, porous stratum where the water can be collected before it injures the field below. A common depth in draining irrigated land is 7 to 10 feet.

For thorough drainage of alkali lands, where protecting drains cannot be employed, 6 or 8-inch laterals placed 660 to 1320 feet apart, making one or two laterals to a " forty," should provide fairly thorough drainage if a porous layer can be encountered at a depth of 7 to 12 feet below the soil surface. The efficiency of such drains will depend upon the prevalence of water and the amount of irrigation employed for the particular texture of soil to be dealt with. A study of subsoil conditions will reveal the presence of porous layers through which water is passing and in which drains can be placed to collect it. These layers must be so deep that drains placed in them will overcome the capillary action between the water-table and the surface.

Studies on the Malheur bottom revealed the fact that a sandy

streak may be encountered at from 5 to 9 feet below the surface, while a quite porous, gravelly layer can usually be found at a depth of 8 to 12 feet. Water comes rapidly into the post-holes from these porous layers in the subsoil; and from these studies it appears that the drainage of these lands is feasible, considering the high amount of plant-food the soils contain, and the favorable climate in which they are located. Similar studies have been made on alkali lands in other places.

TABLE VIII.— AVERAGE PRACTICE FOR LOCATION OF
LATERALS

Soil	Depth	Distance Between Laterals
Clay	33 in.-36 in.	2-3 rods
Clay loam	36 in.	3-4 rods
Silt loam	36 in.-42 in.	5 rods
Loam	36 in.-48 in.	6 rods
Sandy loam	36 in.-48 in.	6-12 rods
Sand	42 in.-48 in.	12-20 rods
Peat	48 in.-60 in.	5-12 rods
Irrigated land	84 in.-120 in.	20-160 rods

TABLE IX.— SOIL SEPARATES IN DIFFERENT SOIL TYPES (U.
S. BUREAU OF SOILS)

	Percentage of Soil Separates		
	Sand	Silt	Clay
Clay	0-50	0-50	30-100
Clay loam	20-50	20-50	20-30
Silt loam	0-50	50-100	0-20
Loam	30-50	30-50	0-20
Sandy loam	50-80	0-50	0-20
Sand	80-100	0-20	0-20
Peat			
Irrigated land			

Drainage of irrigated land in the Klamath Basin is being se-cured most readily by cutoff drains across the slope or below the

canals. There is a layer of water-bearing sand on the chalk rock at a mean depth of about 5 feet, the depth at which drains work best. A 14-inch Austin ditcher is used for the excavation by the U. S. R. Service.

In draining irrigated land, relief wells may be used to bring up water from deep water-bearing gravel to a depth at which it can be reached by drains. Precautions must sometimes be taken in water-logged soil to avoid caving in during construction; and the back filling may need to be tamped, so that irrigation water may leach out the whole soil instead of percolating directly into the drains. Some manholes should be provided to afford an opportunity for observation and for cleaning out roots and silt from the drains.

QUESTIONS

1. Name the factors which determine the proper depth for laterals and distance between them.
2. Explain the relation between depth for drains and distance between them.
3. Explain relations between kind of crop and proper depth for drains.
4. What is the effect of different soil types on proper depth?
5. How do changes in soil strata affect depth for tile?
6. What is the effect of amount and distribution of rain upon drains?
7. Explain the effect of soil texture on distance between drains.
8. For what distance will a tile line affect the water-table in sand? In clay? Within a reasonable time after rains?
9. What materials can be used for bedding over tile lines?
10. Explain the relation of distance between drains to rate of drainage.
11. What effect would deeper drainage have on duration of outflow?
12. What would be a reasonable depth and distance for laterals in loam soil? In clay?
13. What system of drainage would be suitable for flat, heavy clay adjacent to upland?
14. What would be a suitable distance between laterals, to provide drainage for ordinary field crops in tide-land?
15. What arid soil characteristics affect drainage in arid sections?

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CHAPTER VIII

MEASUREMENT OF DRAINAGE-WATER

Measurement of drainage-water may be desirable in order to determine the size of tile or channel needed, to learn the capacity of a given sized tile, or to learn the amount of outflow from a given tile system.

Units and Equivalents. — Water is most dense at 39.3° F. and weighs 62.424 pounds to the cubic foot at that temperature. A cubic foot contains 7.48 gallons. *The inch-foot*, which is 1 inch deep over 1 square foot, weighs 5.2 pounds. *The acre-inch* is equivalent to 1 inch deep over 1 acre, or $\frac{1}{12}$ of 43,560 cubic feet, and equals 3630 cubic feet, or is equal to 1 inch rainfall over 1 acre. The flow from large tiles or the discharge from an open ditch is best expressed in cubic feet each second, or *second-feet*. This refers to the number of cubic feet passing a given point each second of time. An outlet-box 1 foot deep and 1 foot wide filled with water moving at a velocity of 1 foot per second would discharge 1 cubic foot each second. A cubic foot to the second is equivalent to 60 cubic feet a minute, or 3600 cubic feet an hour, being approximately 1 acre-inch an hour, or one acre-foot in 12 hours. The second-foot is approximately $7\frac{1}{2}$ gallons to the second, or 450 gallons a minute.

The quantity of water flowing is always equal to the cross-sectional area of a stream times the velocity, that is, quantity equals area times velocity. Thus, $Q = AV$.

Where A is the area in square feet and V is the velocity in feet to the second, quantity, or Q , will be obtained in cubic feet per second. The area of a stream can always be determined by cross-sectioning. This may be done by holding a tape across the surface of the stream on the smooth part where the channel is clear, and measuring the depth at regular intervals across the stream. This divides the whole area into small sections of

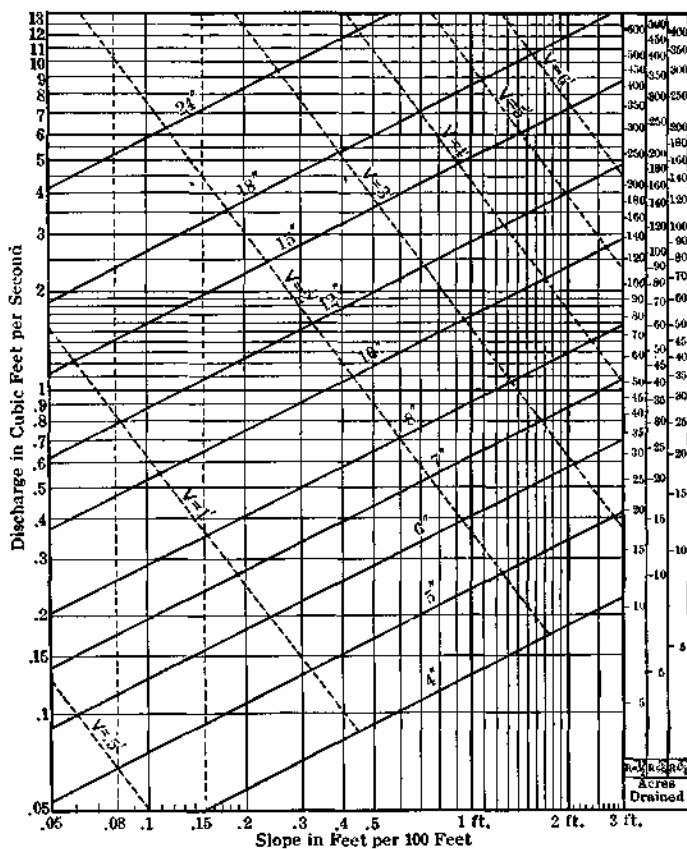


FIG. 31. Diagram showing discharge, and tile size for different slopes, based on Kutter's formula. (Courtesy of Bureau of Agricultural Engineering, United States Department of Agriculture.)

trapezoidal or triangular shape. The area of each section can then be determined and totaled, to secure the cross-sectional area. Taking measurements in decimals of a foot will facilitate calculations for securing the cross-sectional area in square feet. The velocity of a stream can be obtained roughly by chips, by formulas involving cross-section and slope, or more accurately by a current-meter.

Measurement by Chips. — To be measured by chips, a stream should first be cross-sectioned as above described, to determine the cross-sectional area in square feet. A straight, smooth section of channel should be measured off or paced for a definite distance along the stream. A chip should be floated at the upper end of this course and the time it requires to run the measured course of the stream should be noted. Chips should be run at



FIG. 32. Weir and drainage system outlet.

frequent intervals across the stream so that the average velocity is secured. If the average time required for the chip to travel 50 feet should be 25 seconds, the stream's mean velocity would be 2 feet per second. This velocity in feet per second, multiplied by the area in square feet, will give the discharge in cubic feet per second. In small streams the surface velocity should be multiplied by 0.8 or by 0.95 in large deep channels to give more nearly the mean velocity. Instead of this, the mean velocity for different sections of the stream may be secured directly by the use of weighted chips or partly submerged bottles.

Meter Measurements. — The current-meter is an instrument designed to determine the velocity of a stream, and is rated by moving it through still water at different velocities. A table is then prepared from which the velocity in feet per second can be

determined. A current-meter is usually provided with a telephone receiver or electric connection, so that the number of revolutions can be determined by the observer for definite intervals of time. It is customary to arrange the instrument so that a tap is heard or registered for each 1, 5 or 10 revolutions, according to the velocity of the stream and a table which gives the velocity for the observed number of seconds to each revolution. Observations are usually obtained for about 30 to 60 seconds at each of several points across the stream. The mean velocity in any

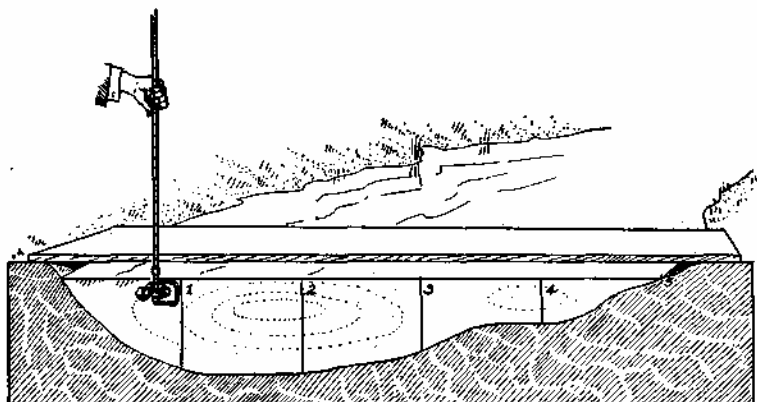


FIG. 33. Measuring velocity of a stream with small current meter.

vertical line will usually be obtained by holding the meter at a depth from the surface equal to $\frac{6}{10}$ of the depth of the stream. It may also be obtained

by taking the average velocities at $\frac{2}{10}$ and $\frac{8}{10}$ the depth. Instead of this the

meter can be slowly raised and lowered during the observation to obtain the mean velocity. The table provided with the meter will give the velocity in feet per second for any interval of time required to make 100 revolutions — corresponding to a multiple of 5 or 10 revolutions during say 30 seconds.

The mean of the two velocities found at each side of a vertical section of the stream, in feet per second, multiplied by the area of the section in square feet, will give the discharge of the section in second-feet.

The sum of the discharges of the sections will give the total discharge.

Formulas for Velocity and Discharge.— Formulas have been developed for determining the flow of water (a) in open streams (6) through pipes and tile-lines, and (c) through standard measuring weirs.

Gravity is the cause of flow of water, whether running down an incline or falling vertically. The formulas for water velocity and measurement of water are based on a formula used to express the theoretical velocity due to gravity,

$$V = CV\sqrt{2gh}$$

in which

V = velocity in feet per second.

g = accelerating force due to gravity, or 32.2.

h = space or head through which the body falls.

C = constant, usually about

This formula applies to orifics only.

Water flowing down an incline encounters resistances of various kinds which tend to make the velocity moderate and uniform. Formulas have been developed by painstaking experiments to represent these factors in streams and pipes.

A. Formula for Open Channels. — The formula usually applied to the pipe or open channel is $V = C\sqrt{rs}$, the Chezy formula with the Kutter coefficient, often called the Kutter formula.

$$C = \frac{41.65 + \frac{0.00281}{s} + \frac{1.811}{n}}{1 + \left(41.65 + \frac{0.00281}{s} \right) \frac{n}{\sqrt{r}}}$$

In this formula, n = a constant depending on the roughness of the channel.

s = fall in feet divided by the length in feet.

r = hydraulic radius = $\frac{A}{P}$ where A is area of

waterway and p is the wetted perimeter of the channel cross-section.

MEASUREMENT OF DRAINAGE-WATER

TABLE X
COEFFICIENT (C) IN KUTTER'S FORMULA

Slope <i>s</i>	<i>n</i>	Hydraulic Radius <i>r</i> in Feet														
		0.2	0.3	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	4.0	6.0	8.0	10.0	15.0
.00005	.010	87	98	109	123	133	146	154	164	172	177	187	199	207	213	220
	.012	68	78	88	98	107	113	126	135	142	148	157	168	176	182	189
	.015	52	58	66	76	83	89	99	107	113	118	126	138	145	150	159
	.017	43	50	57	65	72	77	86	93	98	103	112	122	129	134	142
	.020	35	41	45	53	59	64	72	80	84	88	95	105	111	116	125
	.025	26	30	35	41	45	49	57	62	66	70	78	85	92	96	104
	.030	22	25	28	33	37	40	47	51	55	58	65	74	78	83	90
.0001	.010	98	108	118	131	140	147	158	167	173	178	186	196	202	206	212
	.012	76	86	95	105	113	119	130	138	144	148	155	165	170	174	180
	.015	57	64	72	81	88	93	103	109	114	118	125	134	140	143	150
	.017	48	55	62	70	75	80	88	95	99	104	111	118	125	128	135
	.020	38	45	50	57	63	67	75	81	85	88	95	102	107	111	118
	.025	28	34	38	43	48	51	59	64	67	70	77	84	89	93	98
	.030	23	27	30	35	39	42	48	52	55	59	64	72	75	80	85
.0002	.010	105	115	125	137	145	150	162	169	174	178	185	193	198	202	206
	.012	83	92	100	110	117	123	133	139	144	148	154	162	167	170	175
	.015	61	69	76	84	91	96	105	110	114	118	124	132	137	140	145
	.017	52	59	65	73	78	83	90	97	100	104	110	117	122	125	130
	.020	42	48	53	60	65	68	76	82	85	88	94	100	105	108	113
	.025	30	35	40	45	50	54	60	65	68	70	76	83	86	90	95
	.030	25	28	32	37	40	43	49	53	56	59	63	69	74	77	82
.0004	.010	110	121	128	140	148	153	164	171	174	178	184	192	197	198	203
	.012	87	95	103	113	120	125	134	141	145	149	153	161	165	168	172
	.015	64	73	78	87	93	98	106	112	115	118	123	130	134	137	142
	.017	54	62	68	75	80	84	92	98	101	104	110	116	120	123	128
	.020	43	50	55	61	67	70	77	83	86	88	94	99	104	106	110
	.025	32	37	42	47	51	55	60	65	68	70	75	82	85	88	92
	.030	26	30	33	38	41	44	50	54	57	59	63	68	73	75	80
.001	.010	113	124	132	143	150	155	165	172	175	178	184	190	195	197	201
	.012	88	97	105	115	121	127	135	142	145	149	154	160	164	167	171
	.015	66	75	80	88	94	98	107	112	116	119	123	130	133	135	141
	.017	55	63	68	76	81	85	92	98	102	105	110	115	119	122	127
	.020	45	51	56	62	68	71	78	84	87	89	93	98	103	105	109
	.025	33	38	43	48	52	55	61	65	68	70	75	81	84	87	91
	.030	27	30	34	38	42	45	50	54	57	59	63	68	72	74	78
.01	.010	114	125	133	143	151	156	165	172	175	178	184	190	194	196	200
	.012	89	99	106	116	122	128	136	142	145	148	154	159	163	166	170
	.015	67	76	81	89	95	99	107	113	116	119	123	129	133	135	140
	.017	56	64	69	77	82	86	93	99	103	105	109	115	118	121	126
	.020	46	52	57	63	68	72	78	84	87	89	93	98	102	105	108
	.025	34	39	44	49	52	56	62	65	68	70	75	80	83	86	90
	.030	27	31	35	39	43	45	51	55	58	59	63	67	71	73	77

This formula, although too formidable for ready longhand calculation, is quickly solved by the use of diagrams; or the following table taken from Russell's "Text-Book on Hydraulics," together with Table XXX, will give C, after which the velocity can be more easily computed.

When the velocity is known, the discharge can easily be computed by substitution in the formula

$$Q = AV$$

where Q = the discharge in cubic feet per second.

A— the total cross-sectional area in square feet.

V = the linear velocity of flow in feet per second.

Ramser (9) gives the following values for n , for use in drainage design:

Large channel in rolling country, with high velocity and sufficient low-water flow to prevent rapid growth of vegetation; slick silt lining perimeter; maintenance; clearing each two or three years	0.025
Large channel in rolling country, with sufficient low-water flow to prevent rapid growth of vegetation; moderate erosion; maintenance	0.030
Large channel in flat country, with fairly large low-water flow; no appreciable erosion; annual clearing	0.030
Small channel in rolling country, with small low-water flow; erosion sufficient to cause some irregularities; maintenance	0.035
Small channel in flat country, with insufficient low-water flow to prevent rapid growth of vegetation in lower part of channel; annual clearing	0.035
Large channel with high velocity and large low-water flow; rapid erosion causing large irregularities; no vegetation	0.035
Small channel in flat country, with very fertile loamy soil conducive to rapid growth of vegetation; very small low-water flow, or dry in summer; annual clearing	0.040

Very smooth For use with Table X, the following values of n , the roughness factor for various materials are given:

glazed or planed wood surfaces	0.009
Smooth clean cement	0.010
Rough lumber and new brickwork.....	0.012
Smooth stone, iron and ordinary brick.....	0.013
Drain -tile as ordinarily laid	0.015
Rough ashlar and good rubble masonry	0.017

Firm gravel.....	0.020
Ordinary earth (good condition).....	0.025
Earth channel with stones and weeds.....	0.030
Earth or gravel in bad condition and stream with drift , etc	0.035

Example:

Compute the flow from an open channel in gravel soil, when the bottom width is 6 feet, depth is 3 feet; side slopes are 1 to 1 or 45° and fall is 5.3 feet per mile

$$s = \frac{5.3}{5280} = .001$$

$$n \text{ for gravel} = 0.020$$

$$r = \frac{A}{P}$$

where

$$A = \frac{6 + 12}{2} \times 3 = 27 \text{ sq. ft.}$$

and

$$P = 6 + 2 \times 3\sqrt{2} = 14.5$$

where

$$r = \frac{27}{14.5} = 1.86 \text{ (nearly 2)}$$

Entering the table with above values of n , r , and s we find C lies between 78 and 84 or about 83, hence, since

$$V = C\sqrt{rs}$$

$$V = 83\sqrt{1.86 \times 0.001}$$

$$83\sqrt{0.001860} = 83 \times 0.043$$

$$= 3.57 \text{ feet per second.}$$

and the discharge,

$$Q = 3.57 \times 27 = 96 \text{ cubic feet per second}$$

A simplified form of the Chezy-Kutter formula has been used by Elliott, with good results, for open ditches, using 0.8 of the depth of channel for computing flow, as follows:

$$V = \sqrt{\frac{A}{P} \times 1 \frac{1}{2} h}$$

and

$$Q = AV$$

where

V = velocity in feet per second.

A = area of waterway in square feet.

p = wet perimeter.

h = fall in feet per mile.

Q = discharge in cubic feet per second.

B. Tile-Size Formulas. — There are a number of formulas in use for computing flow of water in pipes, or determining the size of tiles needed for given depths of removal in a given time. Poncelet's formula has been used, but has been largely superseded by the Chezy formula mentioned above, sometimes called

Kutter's formula, $V = C\sqrt{rs}$, in which $r = \frac{D}{4}$ for pipe flowing full or half

full. C varies with n , r and s , and must be determined. The following example will illustrate the use of this formula for tile.

Example:

Compute the flow in an 8-inch concrete drain-tile, flowing half full, when laid on a slope of f inches to the rod.

$$r = \frac{A \text{ in feet}}{p} = \frac{\left(\frac{8}{12}\right)^2 \times 3.1416 \times \frac{1}{4} \times \frac{1}{2}}{3.1416 \times \frac{8}{12} \times \frac{1}{2}} = 0.166 \text{ feet} = 0.2$$

(nearly)

$$s = \left(\frac{3}{4} \times \frac{1}{12}\right) \div 16 \times \frac{1}{2} = \frac{3}{48 \times 16 \times \frac{1}{2}} = 0.0038 = 0.004 \quad (\text{nearly})$$

$$n = 0.015.$$

Entering the table with

$$n = 0.015, r = 0.20 \text{ and } s = 0.004$$

we find the slope lies between 0.001 and 0.010; hence we must get the C for each slope and take average. Using slope = 0.001, $r = 0.2$ and $n = 0.015$, we find $C = 66$; likewise for the steeper slope it is 67, therefore

$$\begin{aligned}
 V &= 66\frac{1}{2} \sqrt{rs} = 66\frac{1}{2} \sqrt{0.17 \times 0.004} \\
 &= 66\frac{1}{2} \sqrt{0.00068} \\
 &= 66\frac{1}{2} \times 0.026 \\
 &= 1.73 \text{ feet per second}
 \end{aligned}$$

$$Q = AV = 3.1416 \times \left(\frac{8}{12} \right)^2 \times \frac{1}{4} \times \frac{1}{2} \times 1.73 = 0.60 \text{ cubic feet per second.}$$

Many diagrams have been proposed for the simplification of the solution of Kutter's formula; but the most convenient one for the drainage student is probably the following, furnished by the Bureau of Agricultural Engineering, U. S. Department of Agriculture.

These diagrams can be prepared for a channel of any shape with any depth of flow, at any slope, and for any degree of roughness, "*n*."

The diagram on page 84 is prepared for tile-drains for which the degree of roughness, "*n*," is 0.015, slopes from 0.05 to 3 feet per 100 feet and diameters of 4 inches to 24 inches. At the right of the diagram is shown the number of acres drained at different rates of runoff and corresponding discharges in cubic feet per second are shown horizontally opposite on the scale at the left-hand side.

For other values of *n* other diagrams will be needed.

These diagrams are plotted to a logarithmic scale, because such a scale gives straight lines instead of curves, which is a decided advantage in using the diagrams.

Any engineer using these scales should plot them to larger scale on mounted paper, to eliminate errors from shrinkage and expansion with change in atmospheric conditions.

The following examples illustrate the use of the diagram.

Example 1. Find the discharge from a 10-inch drain on a 0.5 per cent grade ($s = 0.005$) $n = 0.015$.

Solution:

On the bottom scale find 0.5; follow the vertical line through this figure to its intersection with the diagonal line marked 10". From this intersection, follow horizontally to the left and we find the discharge = 1.2 cubic feet per second. Following horizontally to the right we find this tile-line will drain

approximately 58 acres when the runoff is $\frac{1}{2}$ inch deep, in 24 hours, 45 acres when the runoff is $\frac{5}{8}$ inch in 24 hours and 39 acres when the runoff is $\frac{3}{4}$ inch in 24 hours.

Example 2. What size tile, laid at 0.20 per cent grade, will drain 200 acres when the runoff is $\frac{1}{2}$ inch in 24 hours?

Solution:

Follow up the vertical line representing a grade of 0.20 per cent till this intersects the horizontal line from 200 acres in the $\frac{1}{2}$ -inch runoff column at the right. This intersection falls slightly above the 18" diagonal line. We would therefore use the next larger size or a 20-inch tile to be on the safe side. (This size is not shown on the chart but may easily be interpolated.)

The number of acres served by tiles of given or assumed diameter is found by dividing the discharge by a constant representing the number of cubic feet per second needed to be removed in order to relieve one acre of a given depth in twenty-four hours; *i.e.*, the cubic feet per second per acre corresponding to the given drainage coefficient.

The Drainage Coefficient is the depth in inches to be removed from the drainage area in twenty-four hours. The quantity in cubic feet a second to the acre, for the drainage coefficients commonly used, is as follows:

TABLE XI

Drainage Coefficient. Depth of discharge in inches per acre per 24 hours	Tile constant Second-feet
.....	.0052
.....	0.0105
.....	0.0140
.....	0.0210
.....	0.0315
1	0.0420

The coefficient multiplied by the number of acres will give the total quantity to be handled in cubic feet per second. The quantity determined by formula to be the amount a given tile

is capable of handling, divided by the constant to be used, will show the number of acres a tile is capable of serving. The number of acres from which J inch in depth of water in twenty-four hours will be removed by a system of drainage which has a main 1000 feet long, for the different sizes and grades worked out by the Poncelet formula, as modified by Elliott for use with open soils, is given in the following table¹:

TABLE XII.—NUMBER OF ACRES DRAINED OF J INCH OF WATER
IN 24 HOURS

Grade per 100 Feet in Decimals of a Foot (with Approximate Equivalent in Inches)

Diameter of Tile in Inches	0.05 ($\frac{1}{2}$ inch)	0.10 ($1\frac{1}{8}$ inch)	0.20 ($2\frac{1}{2}$ inch)	0.30 ($3\frac{1}{2}$ inch)	0.50 (6 inch)
		Acres of Land Drained			
5	17.7	19.8	23.5	26.7	32.0
6	28.0	31.2	37.0	42.0	50.5
7	41.1	45.9	54.3	61.6	74.0
8	57.3	64.0	75.6	85.8	103.3
9	76.5	85.6	101.4	114.9	138.1
10	99.5	111.2	131.6	149.3	179.2
12	156.1	174.8	206.8	234.5	281.8
14	228.7	256.1	302.5	343.5	412.9
16	317.8	355.4	420.6	477.4	573.7
18	424.9	475.7	562.2	638.1	767.4

Weirs and Weir Measurements. — Perhaps the most accurate, practical, and economical method yet devised for the measurement of moderate amounts of flowing water is the weir measurement. The weir is a thin notch of definite shape over which the water is caused to flow. The amount of flow depends on the length of crest or bottom of the notch and depth of water flowing over the crest. There are several forms of weirs; but conditions governing their location are the same, the only difference being in the

¹ The figures in Table XII are based on a depth 3 feet to the top of the tile, a length of 1000 feet, and for outlets only. These values are higher than those obtained by Kutter's formula. (Fig. 31.)

shape of notch and in the formula used in computing the discharge. The trapezoidal weir is about the most convenient and is coming to be most generally used in the West. This weir, as its name implies, is trapezoidal in shape, with a straight bottom and with sides having a run of 1 to 4 of rise. A 1-foot trapezoidal weir has a notch-width of 1 foot and is 16 inches wide 8 inches above the crest or base of the notch. The crest and sides should be sharp on the upstream side and the water should have a free spillway. When all conditions are met carefully, this weir will measure water with an error of less than 1 per cent.

Setting the Weir.— In order to prevent leakage around or under the weir, and to add stability, the weir is often provided with a weir-box, which must be large enough in proportion to the notch to eliminate friction and excess velocity of approach. This requires a box or ditch, with a cross-section of at least 7 times the area of the notch. The distance from the crest to the sides should be twice as great as any possible depth of water flowing over the crest; and the distance from crest to bottom should be 3 times the depth of water that may flow over. The weir-plate must be set plumb and the crest level, and the length of the crest should be at least 3 times the depth of water flowing over it. With the proportions given, there will be no appreciable velocity of approach, not over 6 inches to the second. The peg for measuring depth should be located at least 3 feet upstream from crest, to avoid draw down, and should read zero, or be set flush with the water surface when the water is on a level with the crest and just ready to break over. It is not necessary here to go into details regarding principles and mathematics involved in the formula for the weir. Engineers have experimented for years and found that, under like conditions, the same depth always produces the same discharge over a given sized weir. The amount of water passing through each second depends on the area and the gravity head, also the side slope, location of weir, contraction, and viscosity. All of these are represented in the formula which has been evolved as follows:

Quantity equals $3.367 \times$ the length in feet $\times$ the height in feet raised to the $3/2$ power. That is, the height in feet or

decimal of a foot is cubed; the square root is obtained, which is then multiplied by the length in feet and then by the constant 3.367.

In order to save calculations, we usually employ a weir table which gives the discharge for different depths and various lengths, the results having been computed from the above formula.

Method of Using Weir— The head of water flowing over the weir should not be measured until the water has run a little while and the flow becomes steady. It can then be measured by placing upon the peg an ordinary rule graduated in inches. In reading the rule the eye should be held near the level of the water.

How to Use the Weir Table.— Suppose we have a 2-foot weir, and measure the water flowing over it with a common rule and find the depth above the peg to be $4\frac{1}{4}$ inches. Turning to Table XIII in the first column, under the heading "Depth over Crest," we slip down the column to $4\frac{1}{4}$ inches, then horizontally across to the third column under 2-foot weir, and find 1.418 second-feet.

Using figures corresponding to the different sizes of weirs and depths of flow encountered, the depth removed from each acre in a given time can be determined.

A Few Precautions. — Avoid setting a weir close to or just below a curve in a ditch, as this causes water to go to one side.

Do not set a weir close to or just below a headgate where there is a high velocity.

Do not allow water below the crest to back up even with the crest, or confine air underneath, for this lessens the discharge.

Always set the weir perpendicular to the current.

Never allow the pool above the weir to fill up with sediment. -

For the measurement of silt-laden water, or where the necessary fall cannot be obtained, a rating flume or current-meter will be found more desirable than a weir.

The Parshall Flume. — The Parshall or Venturi flume is a substitute for the weir adapted to measurement where the fall is slight (6).

TABLE XIII. — DISCHARGE OF TRAPEZOIDAL WEIRS IN SECOND FEET, COMPUTED FROM THE FORMULA,
 $Q = 3.367 L. H^{3/2}$

Depth of Water on Crest (inches)	1-foot Weir Second-feet	2-foot Weir Second-feet	3-foot Weir Second-feet
$\frac{1}{8}$	.010	.020	.030
$\frac{1}{4}$	.029	.058	.087
$\frac{3}{8}$	.053	.106	.159
1	.081	.162	.243
$1\frac{1}{8}$	.113	.226	.339
$1\frac{1}{4}$	.149	.298	.447
$1\frac{3}{8}$	.188	.376	.564
2	.299	.458	.687
$2\frac{1}{8}$	.273	.546	.819
$2\frac{1}{4}$	.320	.640	.960
$2\frac{3}{8}$	.369	.738	1.107
3	.421	.842	1.263
$3\frac{1}{8}$	.474	.948	1.422
$3\frac{1}{4}$	.530	1.060	1.590
$3\frac{3}{8}$	.588	1.176	1.764
4	.648	1.296	1.944
$4\frac{1}{8}$	.709	1.418	2.127
$4\frac{1}{4}$	.773	1.546	2.319
$4\frac{3}{8}$	.839	1.678	2.517
5	.906	1.812	2.718
$5\frac{1}{8}$	.974	1.948	2.922
$5\frac{1}{4}$	1.044	2.088	3.132

TABLE XIV. — DISCHARGE OF TRAPEZOIDAL WEIRS IN ACRE-
FEET PER HOUR

Depth of Water on Crest in inches	ACRE-FEET IN ONE HOUR			Depth of Water in inches	ACRE-FEET IN ONE HOUR		
	1-foot Weir	2-foot Weir	3-foot Weir		1-foot Weir	2-foot Weir	3-foot Weir
$\frac{1}{8}$	.0008	.0016	.0025	$3\frac{1}{8}$	.0391	.0784	.1176
$\frac{1}{4}$	.0023	.0047	.0071	$3\frac{1}{4}$	.0438	.0876	.1315
$\frac{3}{8}$	.0043	.0087	.0131	$3\frac{3}{8}$	.0486	.0971	.1458
1	.0067	.0137	.0201	4	.0535	.1067	.1600
$1\frac{1}{8}$	.0093	.0187	.0280	$4\frac{1}{8}$	.0586	.1172	.1758
$1\frac{1}{4}$	.0123	.0246	.0369	$4\frac{1}{4}$	.0639	.1278	.1917
$1\frac{3}{8}$	.0155	.0309	.0464	$4\frac{3}{8}$	.0693	.1385	.2079
2	.0189	.0378	.0567	5	.0748	.1497	.2231
$2\frac{1}{8}$	.0225	.0452	.0676	$5\frac{1}{8}$	.0803	.1608	.2414
$2\frac{1}{4}$	.0263	.0529	.0792	$5\frac{1}{4}$	.0863	.1726	.2589
$2\frac{3}{8}$	.0305	.0610	.0915	$5\frac{3}{8}$	.0922	.1864	.2768
3	.0348	.0696	.1043	6	.0984	.1967	.2951

SUMMARY OF WATER MEASUREMENT EQUATIONS

The Quantity (Q) of water flowing is the product of area (A) and velocity (V), or

$$(1) \quad Q = AV$$

Area obtained by sectionizing. Velocity by floats, meter, or formula.

Water, whether running through an orifice or dropping vertically, follows the law of falling bodies, or

$$(2) \quad V = \sqrt{2gh}$$

in which g = acceleration due to gravity = 32.2 feet per second and h = head or height of fall in feet.

This velocity multiplied by the effective area of a submerged sharp-edged orifice, 0.61A, gives its discharge in cubic feet per second, *i.e.*,

$$(3) \quad Q = 0.61A \sqrt{2gh}$$

0.61 = coefficient for effective area.

Weir Formulas:

Weirs are standard openings through which water is measured as it falls. Weir formulas are developed from the equation for falling bodies with terms added to represent area and take care of contraction friction and viscosity.

The equation for discharge from a rectangular weir is

$$(4) \quad Q = 3.33 (L - .2 H) W$$

in which L is the length of crest in feet, H is the height of water on weir peg in feet, 3.33 is a constant to care for contraction, etc. The trapezoidal weir avoids need of correction of area for side contraction and the equation becomes:

$$(5) \quad Q = 3.367 L W$$

To use this, (a) cube the height on weir peg in feet, (6) take the square root of the result, (c) multiply by length of weir crest in feet and (d) then by the constant 3.367.

SUMMARY OF WATER MEASUREMENT EQUATIONS 99

The V-shaped weir is often useful for measuring small streams as outflow from a tile lateral. The formula for it is: Equation for Vshaped weir:

$$(6) \quad Q = 2.54 \, t h^{5/2}$$

in which t is the tangent of half the angle of the notch of the triangle. If the triangle is right-angled, the formula is

$$(7) \quad Q = 2.54 \, h^{5/2}$$

which is simple and excellent for small outflow.

Tile or Open Ditch formula for velocity (V) can be obtained by Chezy's formula which is:

$$(8) \quad V = C \sqrt{rs}$$

in which

C = a coefficient depending on roughness of channel

$$r = \text{hydraulic radius} = \frac{\text{area}}{\text{perimeter}} = \frac{A}{P}$$

$$s = \text{slope} = \frac{\text{fall(inf } t.)}{\text{length(inf } t.)}$$

length (in ft.)

Carrying capacities calculated from this can be read from Fig. 21. For *open ditches* Elliott's formula is simple and gives good results, i.e.,

$$(9) \quad V = \sqrt{\frac{A}{P}} \times 1 \frac{1}{2} h$$

A = area in sq. ft.

p = perimeter, in linear ft.

h = fall in feet per mile

For tile Poncelet and Elliott used the following:

$$V = 48 \sqrt{\frac{dh}{L + 54 d}}$$

where,

d = diameter in ft.

L = length in ft.

h = head in ft.

A simple formula for determination of capacity of smooth pipe is,

$$(11) \quad V = 50 \sqrt{ds}$$

where, d = diam. in ft.

$$S = \text{slope or} = \frac{\text{fall}}{\text{dis tan ce}}$$

To use this choose a promising diameter and make trial calculation. Velocity must always be multiplied by area to get quantity, $Q = AV$.

Divide quantity by drainage coefficient to get area tile will serve.

Coef. of 1/2" per acre = .021 cu. ft. per sec. per acre.

QUESTIONS

1. What are the purposes for which drainage water is measured?
2. Define the inch-foot, the-acre -inch, the second-foot.
3. How should the cross-sectional area of a stream be determined?
4. What different methods are used for determining velocity of a stream?
5. Describe the procedure in determining velocity by means of floats.
6. What is a current-meter and how is it used?
7. What causes flow of water?
8. Define hydraulic¹ radius, wetted perimeter, drainage coefficient, weir.
9. What things tend to retard flow in pipes, in tiles, in open channels?
10. Using a drainage coefficient of 1/2 inch, calculate the number of acres for which an 8-inch tile 2000 feet long, laid on a grade of 0.2 feet per 100, will furnish an outlet.
11. How would a 1-foot trapezoidal weir with 4-inch depth be laid out and cut, if cut out of a 12-inch plank?
12. What precautions are necessary in setting a weir?
13. Calculate the discharge from a 2-foot weir with a head of 0.25 feet.

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CHAPTER IX

SIZE AND GRADE FOR TILES

Size.— In order to secure fairly complete drainage at the lowest possible cost, the size of tiles to use for a main drain should be determined after all data regarding the available fall and the land and water conditions are at hand. Size of tiles refers to inside diameter expressed in inches. The area of cross-section of a tile increases as the square of the diameter. The effect of friction and viscosity is not so great in large tiles, so that an 8-inch tile has about 7 times the capacity of a 4-inch tile with the same amount of fall.

Tile-size depends on (1) slope of drain, (2) area to be drained, (3) friction, viscosity, and eddies, (4) drainage coefficient. Drainage coefficient has been defined, and is affected by the items given here as affecting size of tile. It is, of course, affected by many other things, some of which are discussed in the chapters on soils and soil-water. Some of the factors to be kept in mind are amount, intensity, and seasonal distribution of rainfall, or amount of irrigation, also evaporation, transpiration and prevalence of underground water. It is important to consider the rate of removal of excess water that is necessary to avoid injury to the crops to be grown, the fineness and storage capacity of the soil, and the extent and topography of the watershed and area to be drained. Where surface inlets are used, the tile-size will need to be greatly increased.

There are times when the soil is so dry that 3 or 4 inches of rain will scarcely start the water flowing in the tiles. At other times, when the soil is nearly saturated, it will be necessary to remove the larger part of the rainfall within forty-eight hours. At times, water cannot pass through the soil fast enough, even though the tiles are amply large, so that surface runs or surface inlets are needed. Where these are used, the tile capacity should

be greatly increased. On November 5, 1910, following a very dry season, rains began at the Oregon Experiment Station, and continued until November 10, amounting to 4.94 inches. This rain was just sufficient to start tile-drains on the Experiment Station farm and cause light runoff. The average depth of these drains is about 34 inches, and the water-retaining capacity of this land under field conditions is a little less than 2 inches rainfall for each acre-foot of soil. The size of the tiles must be sufficient

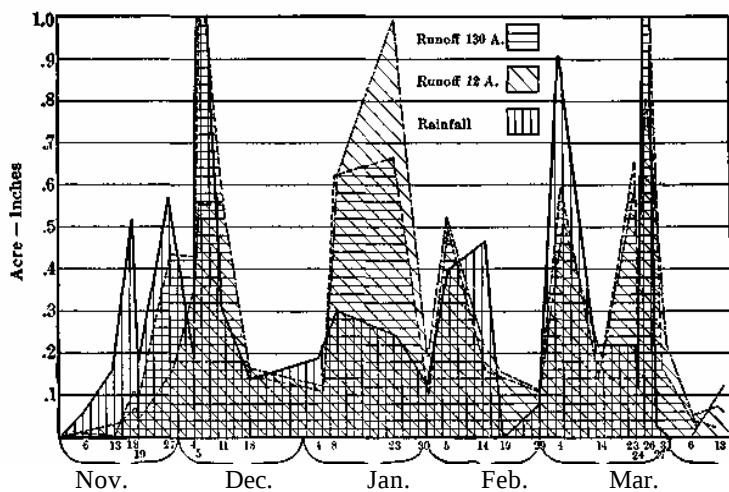


FIG. 34. Hydrograph of rainfall and runoff.

to deal with the heaviest rainfall, excepting only unusually heavy storms.

The main tiles collect water from the laterals; yet it is unnecessary for the main drain to have a capacity equal to the combined capacity of laterals; for laterals rarely flow more than half full.

Yearly precipitation at the Oregon Experiment Station is about 42 inches; the maximum monthly precipitation rarely exceeds 12 inches. Although as much as 2 inches in twenty-four or over 3 inches in forty-eight hours may occur once or twice each winter, there are only eight or twelve days each

year when as much as 1 inch of precipitation occurs in twenty-four hours.

Excess water in more arid sections comes less directly from precipitation, which may total 10 to 20 inches. In the heart of the corn belt the yearly precipitation ranges from 30 to 36 inches.

Runoff depends on soil, topography, vegetation, weather conditions, and other factors discussed in another section. A surface run will be helpful to supplement underdrains, where runoff aids in removal of excess water.

The evaporation from a water surface at Corvallis, from April to October, averages about 27 inches. For the remainder of the year the evaporation is very low. Even in humid sections, annual evaporation from a water surface may exceed the rain fall.

The outflow from underdrains has been studied by the Bureau of Agricultural Engineering, U. S. Department of Agriculture. This Bureau determined the capacity of a large number of tile systems in Illinois and Iowa, where the capacity was regarded as satisfactory by the landowners. The annual rainfall in those districts was 33 to 35 inches, and was fairly evenly distributed. From these studies, it was concluded that underdrains having capacity to remove $\frac{1}{4}$ inch to the acre in twenty-four hours from

the tiled area would provide satisfactory drainage under those conditions.

Other elaborate investigations, taking account of modern tendencies towards thorough drainage, have shown that $\frac{1}{4}$ inch is not enough in

Iowa (14), and should be increased to $\frac{5}{16}$ or $\frac{3}{8}$ inch and fixed according

to local conditions. This conclusion is based on eight years' observations, including systematic rainfall, water-table and outflow measurements from six tile systems serving areas of from 10.8 to 443 acres.

Outflow from 10 acres in Central Park, New York City, was measured for several months under direction of Colonel Waring, who installed drainage for the tract. A portion of the data there secured is presented in the following table:

EXPERIMENTS RELATING TO SIZE OF TILES
TABLE XV.— OUTFLOW FROM TILE SYSTEM
SERVING 10 ACRES — CENTRAL PARK

Period	Precipitation in inches Total for Period	Mean Daily	Maximum Total Daily	Outflow, Total for Period in inches	Acre-inches an Acre in 24 hrs	
					Mean Daily	Maximum Observed
July 13-16	2.20	.73	2.20	.28	.09	.18
16-23	1.23	.17	1.23	.66	.07	.28
23-25	.06	.03	.06	.04	.02	.02
Aug. 3-13	2.40	.24	1.61	.64	.06	.30
13-15	.71	.35	.71	.07	.03	.04
24-27	.26	.08	.20	.60	.20	.28
Sept. 11-20	1.83	.20	1.01	.48	.05	.19
20-26	2.08	.35	1.49	.80	.13	.28
Nov. 22-24	1.07	.53	1.07	.38	.19	.19
Total	11.84			3.95		

This table indicates that underdrains with capacity to handle $\frac{1}{4}$ to $\frac{1}{2}$ inch an acre in twenty-four hours would be satisfactory under conditions existing in New York.

Measurements of the outflow from a tile system draining 3 acres at Uniontown, Alabama, indicate that from 23 to 68 per cent of heavy rainfall was discharged within a few days after rain.

Experiments Relating to Size of Tiles. — Measurement of discharge from several drainage systems in the vicinity of Corvallis, designed to handle $\frac{1}{2}$ -inch rainfall or more for each acre in twenty-four hours, have

been made for the past several years. The outflow has frequently exceeded the $\frac{1}{2}$ -inch coefficient. One tile system with no surface inlets, draining 30 acres of "white land" and having $\frac{1}{2}$ inch capacity, was charged at least

three times in one winter for one or more days. Fairly regular measurements of the discharge from outlets of four drainage systems were made, and the watershed areas were determined from surveys.

Except for the 130-acre area, measurements were made by

collecting water and measuring or weighing it. A weir with automatic register was installed to measure the underdrainage, and flood-water was rated with a current meter. Table XVII gives the greater part of the data obtained.

The 12-acre area is that covered by the experimental drainage system, and has no surface inlets. The area of 130 acres has surface inlets; but the tile system extends under less than half of it. The chief outlet for this large tract consists of 14-inch tiles, and there are also two 7-inch tiles leading to the outlet weir-box. Following the heaviest storm of the year, the runoff from the 130-acre area was 12 second-feet for about twelve hours, and at least 5 second-feet for twenty-four hours. On three or four occasions the total runoff reached 8 second-feet, or twice what the underdrains could carry.

The measurements of runoff and under drainage indicate that in winter the percentage of runoff from small areas in this district is very high, at least 80 per cent of the rainfall. This is largely due to the wet atmospheric conditions, the heavy texture and saturated condition of the soil, and the limited amount of vegetation at this season of the year. The mean daily rainfall and mean runoff, in acre-inches an acre, is shown diagrammatically in the accompanying hydrograph.

The mean maximum discharge appears to be about 5 inch for each acre in twenty-four hours, while the mean discharge is about .3 acreinch for each acre in twenty-four hours.

Plant-Food in Drainage Water.— Samples of the first out-flow in November, and of drainage from the experimental drain outlet in April were collected for analysis. The chemists found about 3 times as much nitrogen in the first outflow as in the second sample. Determinations by Mr. Carpenter of the Oregon Experiment Station follow:

Sample collected Nov. 24, 1915: 9.09 parts per million of nitrate nitrogen, (NO_3).

Sample collected April 7, 1916: 3.60 parts per million of nitrate nitrogen, (NO_3).

The yearly precipitation for Corvallis is 42.4", of which 45 to 77 per cent percolates through the 4-feet soil columns of lysimeter tanks or

drainage bins. Soil with good natural drainage permits heavier percolation. Studies of composition of percolate indicate that the first percolate approximates a displaced soil solution in chemical composition. Lime and manure increase the loss of total leachings and of calcium, magnesium, potassium, sulphate and nitrate. Calcium ion is lost in largest amounts. The quantity lost was 65 to 70 pounds an acre a year. Nitrate is lost at a rate of 25 to 30 pounds, and lime and manure nearly double this loss. Sulphate was lost at the rate of about 50 pounds an acre a year; magnesium, 23 pounds, and potassium 16 pounds. Phosphate was lost in the amount of 4 parts per million, and lime and manure decreased this loss.

The loss of nitrate nitrogen from the famous drainage gauges at Rothamsted, England, has been approximately one pound for each inch of rain, for the last 25 years reported, and for the previous 15 years 1.1 pounds per inch rainfall. The decrease is more noticeable as the total supply in the gauges is reduced. Precipitation contributes some 5 pounds of nitrogen an acre each year at Rothamsted, and no evidence of nitrogen fixation in the gauges has been found. Slight variations with seasonal rainfall and temperature conditions are reported. The 38-year averages for the period 1877-8 to 1914-15 follow:

TABLE XVI.—RAINFALL, PERCOLATE AND NITRATE IN DRAINAGE WATER—ROTHAMSTED

Rainfall Inches	Drainage Water			Nitrate Nitrogen Lost		
	20" gauge Inches	40" gauge Inches	60" gauge Inches	20" gauge Pounds	40" gauge Pounds	60" gauge Pounds
28.94	14.74	15.42	14.78	30.78	26.49	30.04

In underdrained plots of Broadbalk field at Rothamsted, the maximum loss of nitrate is in late spring, while in the drainage gauges it is in autumn after heavy rains begin.

The total rainfall acre received by drainage plots from November

TABLE XVII.—RAINFALL AND OUTFLOW FROM DRAINAGE SYSTEMS

O. A. C. Experiment Station, 1915-1916

Period	PRECIPITATION, (INCHES)		OUTFLOW, MAIN DRAIN COLLEGE FARM 130 A		OUTFLOW EXP. DRAIN- AGE FIELD 12 A	
	Total for Period	Mean Daily	Second- feet	Acre- inches an Acre	Gal. per min.	Acre- inches an Acre
1915						
			In 24 hrs.		In 24 hrs.	
Oct. 30-Nov. 6.....	.50	.07	.01	.00	36	.02
6 13.....	1.15	.16	.01	.00	48	.03
13 18.....	2.62	.52	.08	.01	150	.08
18 19.....	.17	.17	.05	.01	135	.04
19 27.....	4.56	.57	2.36	.43	300	.16
27-Dec. 4.....	1.31	.19	2.36	.43	600	.32
Dec. 4 5.....	1.28	1.28	5.50	1.01	1000	.53
* 5 P. M. 6-8 hrs.....			8.00	1.47	1000	.53
5 11.....	1.87	.31	3.05	.56	1000	.53
11 18.....	.89	.13	.84	.15	330	.18
1916						
18-Jan. 4.....	3.11	.18	.47	.09	1186	.10
Jan. 4 8.....	1.19	.30	3.46	.64	1200	.64
8 23.....	3.67	.25	3.57	.66	2000	1.06
23-6 hrs.....			7.40	1.37		
23 30.....	.87	.12	.53	.10	250	.13
30-Feb. 5.....	2.37	.39	2.55	.47	1000	.53
Feb. 5 14.....	4.16	.46	.90	.17	460	.21
14 19.....	0.00	.00	.77	.14	299	.16
19 29.....	.58	.06	.53	.10	203	.11
29-Mar. 4.....	3.53	.88	3.57	.66	1000	.53
Mar. 4 14.....	2.11	.21	.77	.14	284	.15
14 23.....	1.86	.21	3.57	.66	1122	.60
23 24.....	.12	.12	1.26	.23	561	.30
24 26 P. M.....	3.17	1.57	12.00	2.21	1406	.80
26 27.....	.01	.01	4.50	.83	818	.44
27 31.....	.01	.00	.90	.17	141	.07
31-Apr. 6.....	0.00	.00	.23	.04	112	.06
Apr. 6 13.....	.75	.11	.11	.02	141	.07
13 21.....	.70	.87	.11	.02	112	.06
21 28.....	.46	.66	.08	.01	95	.05
28-May 1.....	0.00	.00	.08	.01	95	.05

*Includes surface runoff

30 to May 1 was 44.13 inches. The total acre-inches discharge an acre was approximately 35.30 or 78 per cent; and the total amount of nitrate nitrogen then removed was 50.62 pounds an acre, worth \$2.28 if nitrogen is valued at \$.20 a pound. Without tiling, the heavy runoff must occur over the surface, carrying rich surface soil with it. Tile-water is clear, while runoff is very clouded. On the sand soil of the Umatilla Branch Experiment Station, Oregon, nitrate is removed at the rate of 150 to 125 pounds per acre annually in the percolate from 6-foot lysimeter tanks. Lyon and Bizzell studied plant-foods removed in drainage, with different treatments, from lysimeters containing clay loam, and found higher nitrate loss in clean cultivated than in cropped soil. According to McHargue, the value of plant nutrients carried into the Gulf of Mexico by the Mississippi River annually is approximately \$4,500,000,000, at prevailing fertilizer prices.

Conclusions Regarding Drainage Coefficient. — Under conditions of 40 inches of rainfall, a coefficient of $\frac{1}{3}$ inch is indicated as suitable for large

fields. For areas of 40 acres or less, where some surface inlets are to be used and little provision is to be made for surface runoff, capacity sufficient to remove $\frac{1}{2}$ inch for each acre in twenty-four hours is recommended.

For average conditions, as in the Central States, capacity to remove $\frac{5}{16}$ to $\frac{3}{8}$ inch an acre in twenty-four hours should be provided. Where the annual rainfall is not over 30 inches, inch per acre is a reasonable coefficient. These figures will vary with conditions.

Table XII shows the number of acres from which $\frac{1}{4}$ inch of rainfall will be removed in twenty-four hours. If $\frac{1}{2}$ -inch capacity is desired the area may be divided by two.

To use the table, find the area to be drained through any point, and choose the size according to the area to be drained and the grade above that point. The tendency is to use larger tile and avoid open ditches, except for large volumes of water. Low-grade sewer-tiles have been successfully used for main drains. The quantity of water flowing in a drain can be determined by measurement with the trapezoidal weir previously

described. A rough estimate of the capacity required can be made by placing a large tile in the ditch and filling in around it with dirt so that the stream will pass through the tile.

Size of Laterals. — A lateral usually drains a strip only a few rods in width. Unless springs are encountered, a 5-inch tile is large enough for average conditions up to 1000 or more feet in length. There is so much advantage in the larger tiles that the slight difference in price of 4-inch compared to 5-inch tiles does not justify use of the smaller size, except possibly for short lines in heavy soil where there is a large amount of fall. A

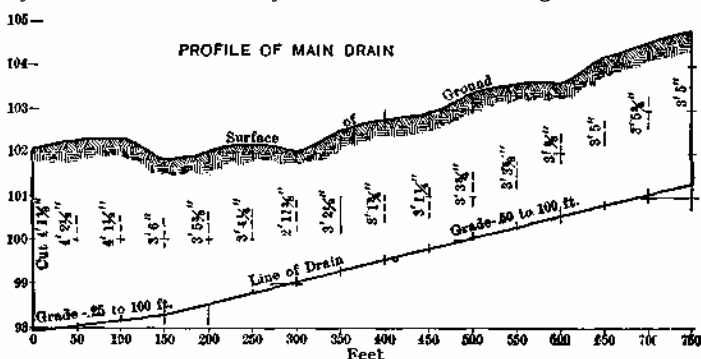


FIG. 35. Profile of the main drain of the system shown in Fig. 29.

greater length gives low capacity due to increased friction in the small tiles. In peat or alkali, where laterals are often 440 feet apart, and perhaps 6 feet deep, a 6-inch tile is needed. The size depends on prevalence of water, or amount of irrigation. Laterals in tide-land should be at least 5 inches.

Grade. — The greater the fall, the greater the capacity. Laterals of 4-inch tile should have a fall of at least 1 inch in 5 rods; and twice this amount, or 2/10 foot for each 100 feet, can usually be secured. A lateral that is to run across a springy slope should have 3 to 6 inches fall for each 100 feet to make the water go through the tile instead of with the slope of the land. Large tiles may be laid with a fall of as little as $\frac{5}{8}$ inch, or .05 feet in 100 feet. Where the fall is less than 1 foot for 100

feet, the grade should be carefully fixed by the use of a leveling instrument. An effort should be made to avoid changing from a steep to a slight grade; and, if such a change is necessary, it may be advisable to install a silt-basin.

QUESTIONS

1. Name factors affecting size of tiles and explain their influence.
2. What capacity or coefficient is indicated by outflow measurements? In different regions?
3. What plant-foods are present in greatest amount in drainage-water?
4. Why would runoff result in more soil injury than outflow through underdrains?
5. What are the advantages of large tiles as compared to open drains?
6. What benefits result from using lateral tiles of ample size?
7. Under average conditions how small and how long may a lateral safely be?
8. What is the relation between the size of laterals and the distance between them?
9. What effect has grade on proper size for tiling?
10. What danger is there in changing from greater to lesser grade, and how can this be overcome?
11. What precautions should be taken where there is a steep grade?
12. What things should a drainage report include?
13. Under what conditions are the following ditching methods practicable: Blasting, sluicing, grading?

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CHAPTER X

CONSTRUCTION OF UNDERDRAINS

When to Tile. — The best season of the year to install a drainage system is late spring. If it is attempted earlier than this, excess water and heavy rains will interfere; and later in the season the soil may become dry and hard, so that it is more expensive to work. Marsh land will be least subject to excess water in late summer, while irrigated land may contain less excess water in early spring before irrigation begins.

The Permanent Survey. — While the entire drainage system should be planned before construction begins, it is useless to set grade stakes for more drains than can be installed during one season, as these will be plowed out, or tramped out by animals in a few months, and will need to be replaced. Where the system is small and there is a fall of more than 1 foot to each 100 feet, the drains may be successfully laid by water-grade, and the amount of tiling needed can be estimated by chaining or care-fully pacing out the lines to be installed.

Accurate data and good construction are necessary to secure the highest efficiency in a drainage system; and, where the land is at all flat, it will usually pay to get a drainage engineer to test the feasibility of the plan, and set grade stakes or "hubs," so that the tiles can be carefully laid to a calculated grade.

In staking out a drainage system, hub-stakes are set at regular 100- or 50-foot intervals, beginning at the outlet. These stakes are set in a straight line, just at the side of the proposed drainage ditch. The "hubs "are driven nearly flush with the surface, and on these the surveyor's rod is held. Guard- or guide-stakes are driven near the "hub "and are large enough to be seen easily. Stakes should be provided in advance.

Where a small amount of leveling is to be done and there is

sufficient fall to obviate the necessity of extreme accuracy, a carpenter's level provided with sights may be used for rough leveling work. A fairly accurate farm-level may be bought for about \$20, while any farmer or group of farmers with considerable drainage to do could provide a much better grade of level costing \$40 to \$60.

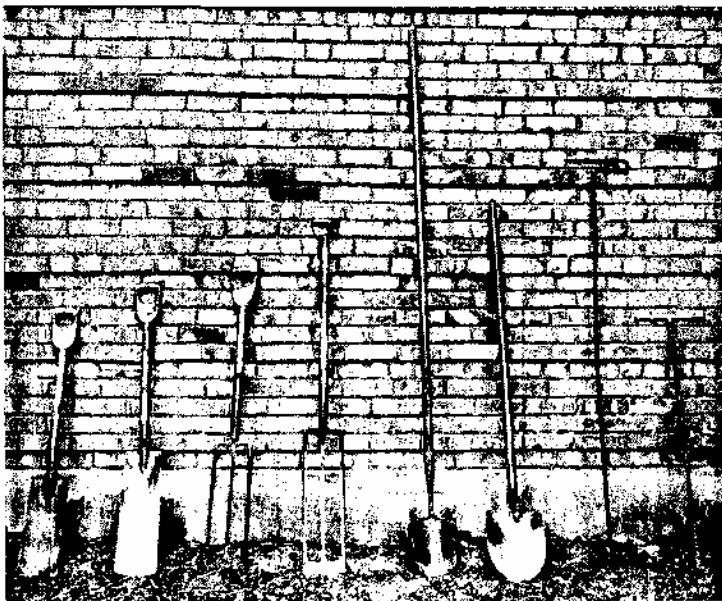


FIG. 36. Tile laying tools. (Courtesy of Iowa State College.)

Drainage Reports. — A brief report should be prepared covering each farm survey, summarizing data secured or developed. This report may well include the legal location and extent of the area, the topographic, soil, and ground water, the rainfall and runoff conditions, and the source of excess water. A plan and estimate of cost should be included, and this should show the number, size and length of tile-lines. Profiles may need to be attached and explained. Recommendations as to the extent of drainage found feasible may be included.

Getting the Tiles. — The survey should determine accurately the number of feet of tile-lines required for the units of the drain age system which are to be immediately installed. After the size of tile is decided upon for the different lines, a tile bill may be prepared and bids secured. The tiles should be ordered in carload lots, if freight is involved, and should be hauled directly from the car to the ditches being distributed along the trenches, within reach of a tiler standing in the trench. (Fig. 37.)



FIG. 37. Hauling and distributing tile.

Trenching Machinery. — Where there are many long parallel lines of tiles to be installed and the land is reasonably firm and

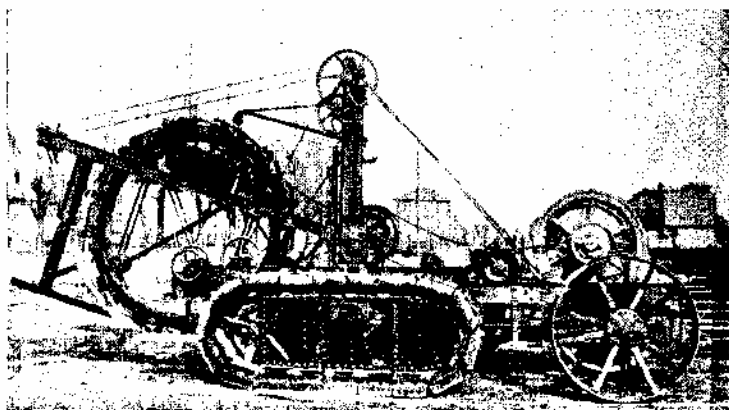


FIG. 38. A traction tile ditcher.

free from structures, stone or hidden logs, a trenching machine may be employed. The wheel or track type of machine (Fig. 38) may be secured by a district or contractor. Horse-drawn ditchers may save money where labor is scarce and where deep

drainage is not required. The V ditcher (Fig. 146) opens up a surface run or removes the surface spading economically, when soil is in condition for plowing and there is plenty of power available. The cyclone ditcher has been used profitably when several carloads of tiles were installed.

The Little Wonder ditcher (Fig. 41) has been used in Western Oregon successfully. A 30-inch

trench has cost $1\frac{1}{4}\text{¢}$ per foot

in silty clay loam, where the farmer furnished a four-horse team and a driver, and the contractor a team and operator.

The mole ditcher is a tool which can be set in the soil at the desired depth and drawn through the land on the grade determined, pulling tiles into the opening it forces in the subsoil. When about 200 feet of tile have been placed, the equipment moves forward and is dug in

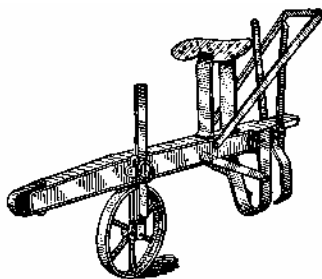


FIG. 39. Ditching plow used for loosening soil in trenches. (Farmers' Bulletin 1131, U. S. Dept. of Agri.)

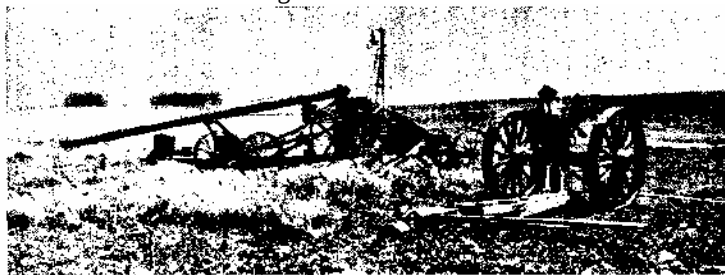


FIG. 40. Mole ditcher. Tiles are pulled into hole made.
(Union Co., Iowa.)

again. The tool is fairly simple and has been successfully used where conditions are favorable.

Lack of labor and increased use of power-machinery increase the demand for trenching by machinery.

Building Ditches with Water. — A scarifying tool similar to a threshing cylinder has been used by Oregon Experiment Station to file loose material for sluicing out so as to convert a surface run into a deep trench.

The tool is drawn by a team on each bank. A few second-feet of flowing water and a fall of several feet per mile are necessary for good results. The outlet ditch at Malheur Experiment Field was sluiced to a depth of 10 feet without leaving unsightly spoil banks.



FIG. 41. "Little Wonder" ditcher being viewed by Dr. S. H. McCrory

Blasting Ditches for Drainage. — Drainage channels in marshy locations have been improved by blasting. The following statement is



FIG. 42. Building a drainage ditch with the Purvis scarifier.

based on notes furnished by F. E. Price, formerly Soils Extension Specialist, Oregon Agricultural College.

Explosives may be useful in changing channels of small streams or constructing new channels under marshy conditions. Place charges in a straight line 12 to 18 inches apart to set off successively by propagation.



FIG. 43. This storm ditch was started with a plow and grader, and has since sluiced out.

Or, place 2 to 4 feet apart, using a No. 6 electric cap with each charge, and connect 15 to 50 or more together, depending on the size of the blasting machine and explode them all at one time. Blasting is not adaptable

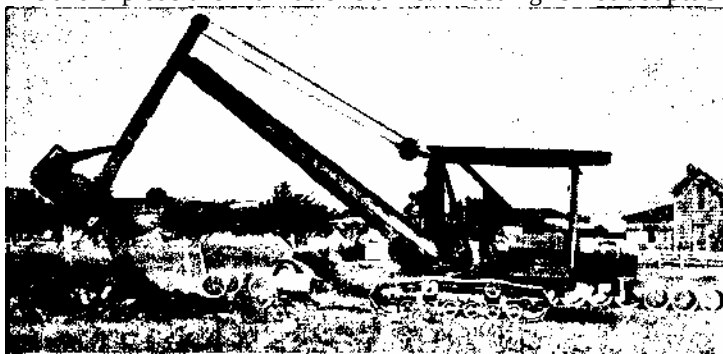


FIG. 44. Small excavator constructing a main drain.

for ditches less than 3 or 4 feet wide and 3 feet deep. The size can be increased to 8 or 10 feet wide and probably 6 feet deep. The cost for explosives, including electric caps, for the smaller ditch will

be about \$0.04 per linear foot of ditch and the larger ditch from \$0.08 to \$0.10 per linear foot, depending on soil conditions.

Hand Trenching. — The use of the plow in starting the trench is favored only in tough sod where the work is done by unskilled hand labor. A trench 33 to 36 inches deep can be provided by removing two courses with the tile-spade, and should be started about 11 or 12 inches wide at the top. A three

-course ditch will need to be 16 inches wide at the surface. In starting the ditch, a guide string is stretched on the ground at one side of the stakes.

At bends, a $\frac{1}{4}$ inch rope

should be laid on the ground in a smooth curve. An 18-inch, square-pointed tile-spade is commonly used for removing the first spading. (Fig. 36.) The trench should be kept straight and the sides smooth and plumb. A

good spades man will set the spade a little angling, and will not need to trim the side of the trench much with a spade. A skilled worker will not leave much loose dirt in the bottom of the trench. If the weather is dry, crumbs should be left in the trench until the second spading is to be dug (to prevent the soil from getting dry and hard). A round-pointed shovel can be used to remove this loose dirt, after which the second spading is dug within an inch or so of the proposed grade. For removing the second spading, some workmen prefer a round-pointed tile-spade, which makes the trench a little narrower at the bottom.



FIG. 45. Laying eighteen-inch main

The gauge-line should be set before the second spading, so that the ditch will in no case be cut below the proposed grade-line. The last inch or two is taken out with a shovel and tile-scoop, leaving a smooth, firm tile-base.

The Use of the Grade-Lath. — The depth to dig at each station is measured from the top of the hub-stakes. In order to dig a trench to grade, or with a finished uniform tile-base between these grade points, it is best to use a gauge-line and gauge-sticks, as shown in Fig. 46. Grade-bars are set over each hub-

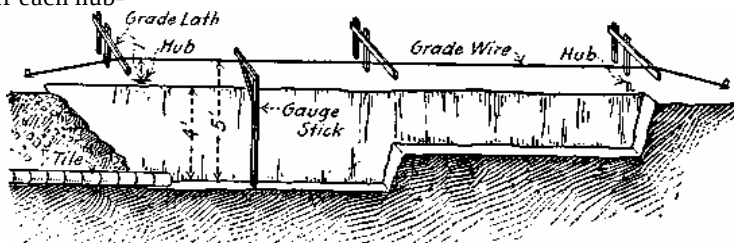


FIG. 46. Sketch showing use of line and gauge in finishing tile trench to an accurate grade.

stake at a uniform and convenient distance above the proposed tile-base. A wire is stretched over these grade-bars a uniform distance above the proposed grade-line and parallel to it. If the grade-bars are 4 feet above grade, the ditch should be trimmed out until a 4-foot gauge-stick, when held in a vertical position, will just reach from the string to the bottom of the trench. To determine the height at which to set the grade-bars, subtract the depth of the cut from the length of the gauge. Grade-bars may be set across the ditch, or at one side with a cross-arm extending out even with the near edge of the trench. A No. 18-gauge galvanized wire makes a good gauge-string, as it is light and strong as well as durable. In cutting through high ridges, a longer gauge may be required. The gauge-line must be kept tight. The following table for converting decimals of a foot into inches is convenient for converting the cut and gauge-height for ready use by farmers.

TABLE XVIII. – EQUIVALENT VALUE OF INCHES AND DECIMALS OF A FOOT

In.	0	1	2	3	4	5	6	7	8	9	10	11
0	.00	.08	.17	.25	.33	.42	.50	.58	.67	.75	.83	.92
$\frac{1}{8}$	.01	.09	.18	.26	.34	.43	.51	.59	.68	.76	.84	.93
$\frac{1}{4}$	.02	.10	.19	.27	.35	.44	.52	.60	.69	.77	.85	.94
$\frac{3}{8}$	.03	.11	.20	.28	.36	.45	.53	.61	.70	.78	.86	.95
$\frac{1}{2}$	.04	.13	.21	.29	.38	.46	.54	.63	.71	.79	.88	.96
$\frac{5}{8}$	.05	.14	.22	.30	.39	.47	.55	.64	.72	.80	.89	.97
$\frac{3}{4}$	.06	.15	.23	.31	.40	.48	.56	.65	.73	.81	.90	.98
$\frac{7}{8}$	.07	.16	.24	.32	.41	.49	.57	.66	.74	.82	.91	.99

Laying the Tiles. — Tile-laying should start at the outlet and proceed upstream, as soon as the first section of trench is finished

to grade. A careful workman should be selected to handle the tile-scoop and shovel just ahead of the tile-layer. A tile-scoop should leave a firm tile-base and a little running water will help to make the tile-base smooth. A carefully finished trench facilitates the laying of tiles. The grade should be tested for every length of tile, and the pieces should be placed in a straight line, with the long side tightly at the top



FIG. 47. Finishing trench to grade, and up, so that the joints fit laying tile- (Courtesy Iowa State College-)

side and are nearly flush at the lower inside edge. An opening of 1 inch is allowable; but larger openings should be covered with fragments of broken tiles, called "bats." The tiles may be ro-

tated to fit, and imperfections in tiles may be taken advantage of in making slight turns. Ill-shaped, cracked, and broken tiles should be discarded. Curves can be fitted by carefully chipping off the inside edge of the tile with a chisel and hammer. The " Y's " can be constructed, but it is best to order these when ordering the tiles.

Where quicksand or muck makes a soft bottom in the trench, it is best to lay the tiles on a board or in a " V " trough. sometimes the trench may, with advantage be excavated below grade and back-filled with gravel.

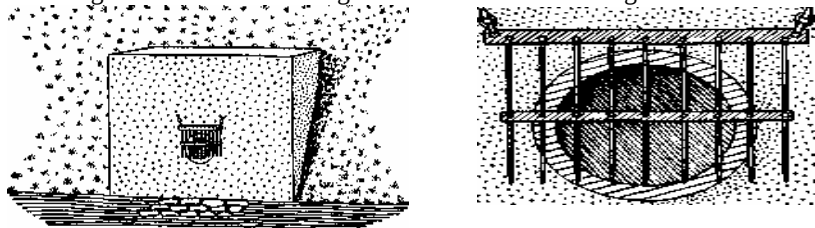


FIG. 48. Tile outlet with hinged guard screen. Horizontal rods would catch less drift.

Corrugated iron pipes, which come in long sections with facilities for securely banding the joints, are coming into extensive and successful use in unstable trenches. They may be had either perforated or unperforated. In extreme cases, concrete may be used. Clay, burlap, or straw may be used to prevent quicksand entering the joints. Gravel or sods may be used around the tile to aid the entrance of water from heavy soil into the tile-lines.

Inspection of the drains before filling should be made by the landowner or engineer, to see that no inferior pieces have been used, that there are no wide joints which appear unprotected, and that the tiles are laid true to grade. A level can be used to test the line, at frequent intervals, for dips or swells in the grade. If muddy water is encountered in the trench, it may be dammed up and held back, until it can be passed through the tile-lines in quantities sufficient to avoid silting. Where the ditch banks are unstable, it may be necessary to resort to curbing or to

blinding the tiles each evening. Precautions should be taken against damage by storms occurring at night during construction.

Filling the Trench. — After inspection, tiles are blinded by a workman who stands beside the trench and shaves mellow dirt from the sides of the ditch, with a spade. A layer of mellow dirt, 3 or 4 inches deep, prevents the tiles from rolling out of line. Plowing off the shoulders of the trench, with a plow that is equipped with long eveners, will put the surface soil in the lower part of the trench. Other tools used for filling trenches are Vcrowders,

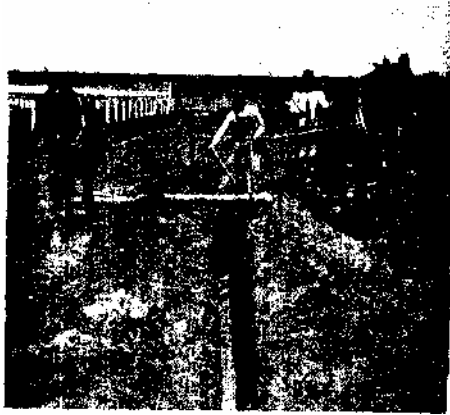


FIG. 49. Filling the tile trench with a plow. (Courtesy Iowa State College.)

which are shod, light road-drags, and light road-graders (Fig. 50). Filling is more readily accomplished before



FIG. 50. Filling the tile trench with a road grader. (Courtesy Iowa State College.)

the dirt has become compact and settled.

Tiling contracts are frequently let at a stipulated price per 100 feet or per rod. The contractor usually furnishes the tools and the landowner furnishes the tiles to be used along the

proposed drain. Whether board is to be provided, and whether the trench is to be completely filled, should be stated in the agreement. The contractor is usually required to begin at the outlet to lay true to grade, and to pursue the work with due diligence. Arrangements are frequently made for

securing pay for a part of the finished work during construction.

While the data are fresh in mind, and before the tiles are hidden, a sketch should be made of the tile-lines, showing their length and depth, and the distance between them. A compass can be used to locate the bearings of different tile-lines; and permanent landmarks, such as trees and property corners, should be referred to, so that any part of the drain system can be located in after years. This is a great help in locating any obstruction or in constructing any additional laterals later. Maps may be simple, but should be definite. A memorandum of the items of cost should be filed with this map.

There are numerous details which must be attended to when tiling, if the drainage system is to be permanently successful. A few important points upon which numerous inquiries have been received are here discussed.

Outlets. — It is of primary importance that the drainage system have a good outlet. It has been said that a drainage system without an adequate outlet is like a man who is "all dressed up with no place to go." Where the outlet is sub-merged, the velocity of the outflow is checked, and sediment is likely to collect and clog the drains. The water should have a free spillway at the outlet. A partly submerged outlet can be kept clear if there is a considerable volume of water and velocity of flow, and if a barrel or box is provided for collecting sediment and is cleaned out, perhaps twice a year. The submerged outlet, however, is not desirable, as the land will never drain below the level of the water in the outlet.

The outlet pipe or tile should be vitrified, or else a corrugated culvert should be used. Such material is not affected by freezing or the tramping of animals. The end of the outlet should be screened, as in Fig. 48, with $\frac{1}{4}$ inch iron rods, placed about 1 inch apart, to prevent rodents from

entering the tile. Where the outlet is submerged at times, it is advisable to provide an automatic flap-gate, hinged at the top so as to close during times of high water, or when the drainage ceases in the summer. A small bulkhead should be provided at the outlet to force the

water to run out through the tile, instead of cutting out around it. This will also retain the earth bank and serve as a monument to mark the location of the outlet. The footing should extend out below the outlet pipe, to form an apron on which the tile may discharge without causing erosion.

Silt-Basins. — Silt-basins are less used than formerly in the East, but are essential in draining irrigated land. Silt-basins are small cisterns or manholes in the drains, extending to the surface from a foot or more below the tile-grade. They are usually provided at fence corners, where two or more lines of tiling join, or at roadsides. Silt-basins afford a means of collecting and cleaning out silt, and to be of value require periodical cleaning. They help to collect

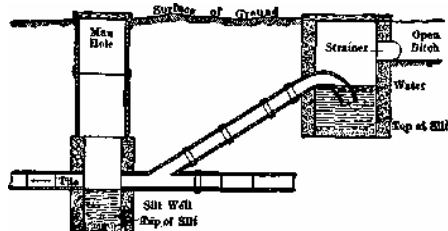


FIG. 51. Surface inlet and silt basin,

surface flood-water quickly, prevent the drain from becoming clogged, and may sometimes be arranged to afford watering-places for the stock. Silt-basins also permit inspection of the tile-lines, and may increase the head of water on the outlet drain in time of high water. A small silt-basin can be constructed by placing a 12-inch sewer-tile, having the required outlets, on end. For larger silt-basins, brick or concrete may be used.

At the Oregon Experiment Station, it was found convenient to construct silt-basins or manholes of concrete. The soil is used for the outer form, and the inner form is made of staves, like a silo, one of the staves being beveled so that it can be removed after the concrete has set. The form makes the manhole 5 feet deep and 3 feet in diameter, with a 20-inch opening in the top, which may be covered with a concrete lid. The walls are about 4 inches thick. The tile-lines are already in place when the silt-basin is constructed; the form is set tightly against the tiles emptying into the silt-basin.

A surface inlet to the silt-basin may be provided. The water should be screened and brought in on a grade, to prevent roiling the sediment with the water in the silt-basin. A few cubic feet of gravel or broken tile in the trench will make a fair inlet at the head of the drain. Surface inlets are apt to clog or admit silt, and should seldom be employed unless there is assurance that they will be faithfully inspected and maintained. (Fig. 51.)

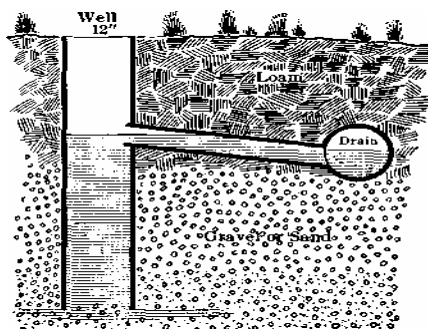


FIG. 52. Relief Well.

Straw or sods in the trench may serve better to aid the entrance of water into the tile.

Relief Wells.—Wells are frequently used to collect the water in a deep gravelly stratum where it is under pressure, as in irrigated or seeped land, and to bring it up to within reach of a conducting drain collecting (Fig. 52). Short laterals may lead to this well; and occasionally

a windmill may be used to elevate water to the outlet tile-lines, where elevation for gravity drainage does not obtain.

Junctions. — The laterals may be laid out perpendicularly to a main drain, but should join the main with a curve, so that the connecting tile or "Y" will have an angle of about 30 degrees, as in Fig. 53. The curve should have a radius of about 5 feet. There should also be a drop where the lateral joins the main, to permit free discharge into the main drain.

Obstructions. — The principal obstructions occurring in tile-lines are small animals, roots and silt (Fig. 54). Protecting all exposed ends of the tile system with screens or broken pieces of tile will prevent small animals from entering. Roots of trees, such as willow, elm, tamarack and soft maple are troublesome.

Cultivated plants, such as alfalfa, grapevines and kale also give trouble where spring-water runs in a tile-line throughout the growing season. Water-loving trees within 20 or 25 feet of the drain should be girdled or cut down, or else the tile should be very carefully cemented at the joints where the drains pass within this distance of the tree. Unless this sealing is very carefully done, however, it will not be effective. Silt will be less



FIG. 53. View of Y-tile in trench properly laid. State College.)

Troublesome in large tiles. Small tiles must be laid true to grade to prevent trouble; the carrying capacity will be greater, and friction will be less if the lower inside lines of the tiles are flush.



FIG. 54. Drain filled with roots from adjoining willows. (Courtesy Iowa

The outlet bulkhead will protect against caving; vitrified tile or corrugated metal pipe at outlets against frost injury; and a tide gate against back-water and silt. Covering the tile where it crosses under a gutter or other low surface unavoidably, with a little soft earth and then a plank, will protect against breakage due to tramping by stock or to tractor operations. Careful cementing of joints and deep drainage will lessen root trouble, where valuable trees or other growths are to be retained and not cut down.

To locate obstructions, dig holes in several places over the tile. A tile-map and an end-gate rod will be of value in looking

up and probing for tile-lines. Below the obstruction, the water will not rise in a dug hole but will fall away into the tiles. Above the obstruction, the water will rise and stand in the hole. The tiles can be uncovered above and below the obstruction, and cleaned out with jointed sewer-rods or with a long, limber pole or a wire cable frayed out into a wire brush at the end.

A tile-line, to be permanently successful, must be given some attention. Inspection and cleaning out of outlets and silt-basins should take place at least twice a year, in the fall before the rains begin and again during the highest water of the season.

QUESTIONS

1. What seasons are suitable for installing a drainage system?
2. What data should the permanent survey provide?
3. Under what conditions would ditching machinery be suitable?
4. What different types of machines are in use?
5. Describe the procedure in constructing a ditch with spades and shovels.
6. Under what conditions should a plow be used?
7. How wide should a 3-foot trench for lateral tiling be started at the surface?
8. Describe the method of setting the grade-line.
9. How is the grade-lath used in laying to grade?
10. What is the tile scoop or "crummer," and how is it used?
11. Why do we begin at the outlet in laying tiles?
12. Describe operations of laying in a straight line? Around a curve?
13. How is a lateral joined to the main tiling?
14. How may quicksand be kept out of tiling?
15. What is "blinding in," and how is it accomplished?
16. Describe a good method of back-filling.
17. What items should be included in a tiling contract?
18. Describe the construction of a good outlet.
19. Under what conditions should a sluice-gate be provided?
20. What purpose may a silt-basin serve, and how is it constructed?
21. Describe the construction of a surface inlet. A relief well.
22. What is the purpose of a relief well, and how is it built?
23. What are the common causes of obstructions in tiling?
24. How may obstructions in tiling be located and removed?

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CHAPTER XI

COSTS AND PROFITS OF TILE-DRAINAGE

The cost of drainage varies greatly with the kind of soil, size of tiles, thoroughness of drainage, method of construction, and labor conditions. It is necessary, first of all, to determine the number and size of tiles required before making a definite estimate of cost.

Costs. — The cost factors to be considered in the tile-drainage system are (1) cost of materials, (2) cost of labor, (3) cost of delivery of materials, (4) cost of depreciation of the necessary-plant, (5) cost of financing the contract, (6) probable damage claims and legal expenses, (7) rights of way, and (8) engineering and contingencies.

From the standpoint of the landowner, however, these usually resolve themselves into (1) delivered cost of materials, (2) cost of digging, laying and back-filling, and (3) incidental expense.

Costs of Materials for Tile-Drains.— The principal materials needed for the construction of tile-drains are tile, gravel, cement, grates, sewer-pipe, corrugated pipe and specials, such as tile Y's and sewer-pipe T's. As a rule, the cost of tiles delivered on board the railroad cars at the factory station is fixed by the published price of the tile companies. These published lists are usually subject to a cash discount, sometimes as great as 50 per cent.

The Tile Bill.— From the permanent survey, a tile bill should be compiled, showing the number of feet of different sizes of tile required for each main and lateral and the total number of different sizes to order. In addition to the general tile bill, a separate bill of pipe specials (Y's and T's), corrugated iron, or vitrified clay outlet pipe, gratings, etc., can be made up. The tiles should be ordered in carload lots for delivery to the nearest railroad point, and the shipper should be responsible for breakage in

shipment. Table XIX shows the comparative average cost of clay and concrete tiles, and sewer-pipe, after the discount has been subtracted.

TABLE XIX.—COST OF MATERIALS FOR TILE-DRAINS (1930)

Diameter of pipe in inches	Clay Tile		Weight in lbs. per ft. tile	Concrete Tile		Sewer Pipe	No. ft. per ton	Average car-load in ft.
	Cost per 1000 ft. Illinois	Oregon		Cost per 1000 ft. Oregon	Weight in lbs.	Cost per ft.		
4	37.50	33.75	6½	45.00	7½		334	6500
5	48.50	40.50	10		11		250	5000
6	65.00	60.00	12	72.00	15		182	4000
7			15		18			
8	116.00	95.00	18	100.00	21		111	2400
10	180.00	175.00	27	160.00	32	.32	80	1600
12		260.00	36	240.00	40	.48	60	1000
14			48		50		56	800
15			50		60	.60	38	500
16			60		85		28	400
18		360.00	70		100	.80		
20			90		116			
22			110		142			
24			124		186	1.20		

Freight. — Where the farm is some distance from the tile plant, tile should be ordered in car lots. Two or more farmers may pool orders where less than a car of tile is required for the individual farm. The tile maker will usually be in better position than the farmer to obtain cars promptly, or to secure transportation at the lowest rates. Auto trucks may be available for moving tile in less than car lots, or for transporting them directly from factory to field. Due to the bulkiness of tile, the rate for the minimum car weight will usually apply.

For example, in Willamette Valley, Oregon, freight on tile for points within 50 miles of the factory is currently \$21 per

minimum car load, or \$25 for hauls of 50 to 100 miles. For similar distances the freight rate for drain tile is \$0.06 and \$0.085 per hundred, respectively.

Gravel and Sand.— The cost of gravel and cement for outlet structures will depend on local conditions. Gravel may often be obtained at a nominal cost at a nearby pit, so that the hauling will be the principal item.

Cement is sold by the bag or barrel. The price depends on the distance from the factory and the purchasing value of the dollar at the particular time. At present (1930) the prices of cement by the barrel in various cities of the United States are as follows:

TABLE XX.— CEMENT PRICES AT DIFFERENT POINTS, OCT. 1, 1930, DOLLARS PER BARREL

	Current Oct. 1, 1930	One Month Previous	One Year Previous
<u>Boston.</u>	\$2.40	\$2 30	\$2 30
<u>Cedar Rapids</u>	2.23	2.24	2.24
<u>Chicago</u>	1.95	2.05	2 05
<u>Cleveland</u>	2 04	2 24	2 24
<u>Cincinnati</u>	2 14	2 22	2 22
<u>Dallas</u>	2.15	2 15	2 15
<u>Davenport</u>	2.14	2.24	2 24
<u>Denver</u>	2.61	2.55	2 55
<u>Detroit</u>	1 95	1 95	1 95
<u>Duluth</u>	2.04	2 04	2 04
<u>Indianapolis</u>	1.99	2.09	2.09 2
<u>Jersey City</u>	2.60	2.25	25
<u>Kansas City</u>	2.60	2.20	2 82
<u>Los Angeles</u>	1.92	2.66	2 76
<u>Milwaukee</u>	2 10	2 20	2 20
<u>Seattle</u>	2.25	2.70	2 70

It may be necessary to make an allowance for freight in addition to the prices indicated in the table. The minimum weight for a carload of tiles is 30,000 pounds, and the average weight of a carload is about 40,000 pounds. As tiles are rather bulky, a ton makes a fair wagon-load. About 500 4-inch tiles or about 200 6-inch tiles can be hauled at one load. Two men with

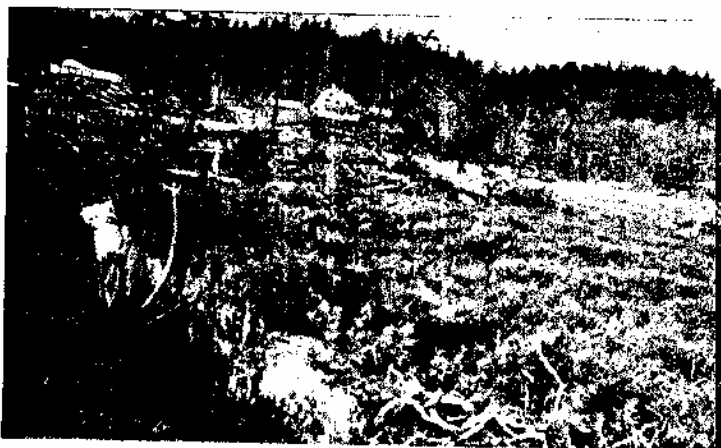


FIG. 55. Land before drainage, Astoria Experiment Station, Oregon.

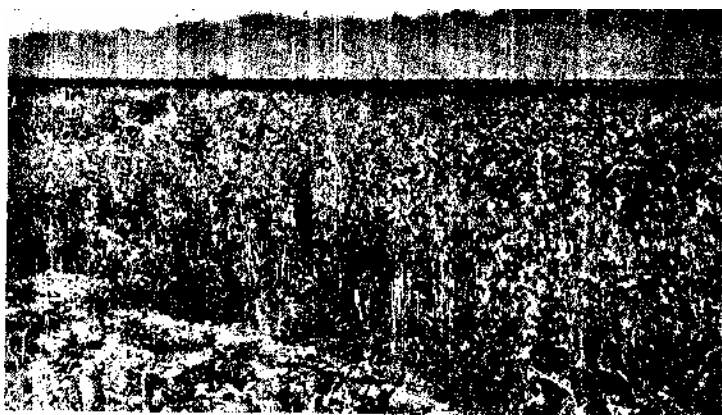


FIG. 56. Same land as shown in Fig. 55, after drainage, growing a crop of oats and peas.

wagons, when hauling to the same field, can assist each other in loading and unloading.

Trenching — Digging the trench, laying the tiles and blinding in with 3 or 4 inches of mellow dirt commonly costs, in the

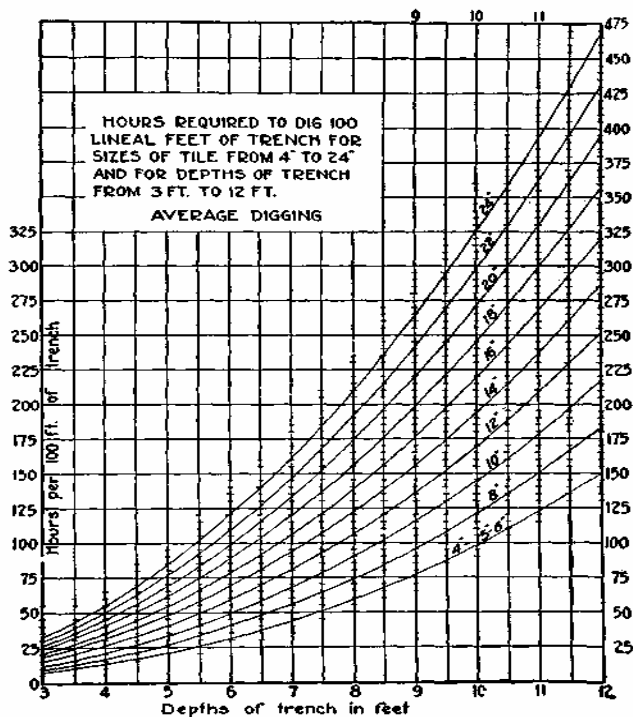


FIG. 57. Diagram showing man-hours required per 100 feet of trench; (Courtesy University of Minnesota.)

Willamette Valley, from \$0.40 to \$0.60 a rod. The latter price frequently includes filling the trench. Reports on tile-drains in the Willamette Valley, aggregating 100 miles of tiling, show

that the average cost for digging and laying for each rod has been \$0.30. The cost of digging and laying varies greatly with the kind of soil, size, depth of trench, and difficulties encountered. Table XXI, arranged by Professor H. B. Roe, of the University of Minnesota, shows the relation between depth, size of drain and hours of labor for each 100 linear feet. See also Fig. 57.

TABLE XXI

MAN-HOURS REQUIRED TO DIG 100 LINEAR FEET OF TRENCH FOR SIZES OF TILE FROM 4-INCH TO 24-INCH, AND FOR DEPTHS OF TRENCH FROM 3 FEET TO 12 FEET (Average Digging — 60 Work Units per Hour. Average of 14 Projects)

Diam. of Tile	Hours per 100 linear feet for depths of trench shown on next line									
	3-ft.	4-ft.	5-ft.	6-ft.	7-ft.	8-ft.	9-ft.	10-ft.	11-ft.	12-ft.
Inches										
4, 5, and 6.....	7.32	13.22	21.20	31.35	43.95	59.33	77.38	99.03	123.00	150.95
8.....	9.57	17.45	27.22	40.98	56.87	74.08	96.23	121.42	150.47	183.17
10.....	12.27	21.58	34.06	49.13	67.85	90.12	115.87	145.43	178.67	217.70
12.....	15.02	26.12	40.27	58.67	80.65	106.13	135.97	169.67	208.73	251.50
14.....	17.75	30.97	47.65	68.33	93.47	122.73	156.52	195.00	237.09	287.04
16.....	20.62	35.52	54.62	78.18	106.32	139.18	177.02	220.72	268.12	322.15
18.....	23.38	40.32	61.82	88.28	119.90	155.52	195.13	246.07	298.85	357.73
20.....	26.55	45.32	69.28	98.63	133.32	173.67	220.25	272.02	329.88	395.45
22.....	29.58	50.62	77.12	109.28	147.12	191.75	241.93	298.43	362.37	431.95
24.....	32.90	55.68	84.70	120.12	161.77	209.32	264.25	325.50	393.73	469.57

After Minn. Agri. Exp. Sta. Tech. Bul. 47.

A study of the cost of tile-drainage reported by the Minnesota Agricultural Experiment Station in 1927 for 18 projects including over 400,000 feet of tile-lines and representing an investment of nearly \$60,000 or \$49.84 per acre drained, shows the following distribution of expense.

Filling the trench with a plow or road-drag has been done in Oregon for \$0.10 or \$0.12 for each hundred feet. Where the filling must be done by a more laborious process, it may cost \$0.20 to \$0.25 a hundred feet.

To these items should be added 5 per cent for surveys and superintendence, or 10 per cent, including outlets, silt-basins, tools, and miscellaneous expenses.

The length of tile-lines required for each acre, if laid in parallel

lines and 4 rods apart, will be 40 rods; if 6 rods apart, 30 rods of tile-lines will be required. At a total cost of \$0.75 to \$1.00 a rod for laterals, this would mean \$30 to \$40 an acre for thorough drainage of the wettest areas on the farm. It rarely happens that more than 25 per cent of the average farm will require such thorough drainage. More frequently, wet swales or springy spots are drained with a random system of tile-lines, making it possible to work the whole field at one time, as well as increasing the production of the low area. In order to direct attention more fully to the costs and profits connected with drainage, a few typical examples of actual costs and results from different sections of the state are here given.

TABLE XXII.—COST OF TILE-DRAINAGE IN MINNESOTA

	Fractio	Per	Per	Per 1000'
Engineering and Supervision . .	8.3	\$4.15	\$12.23	14.20
Tile	32.5	16.22	47.77	
Freight.	7.7	3.85	11.34	
Hauling and distribution	6.0	3.00	8.83	28.38
Trenching, laying and blinding	39.7	19.76	58.18	155.64
Refilling trenches . .	3.9	1.92	5.65	7.55
Outlets	0.8	.37	1.10	.84
Miscellaneous	1.1	.56	1.65	1.38

Freight ran \$0.14 per carload per railroad mile.

Hauling cost \$0.47 per ton mile.

Cost of average digging for different sizes and depth in Minnesota follows.

Results from Tile-Drainage in Oregon. A drainage system was installed by the United States Government in 1908, on a 72-acre field of "white land" 1 mile south of Albany. From 3- to 10-inch clay tiles were used, the depth varied from 3 to 4 feet, and the distance between drains was purposely varied from 60 to 150 feet. Grades ranged from 0.2 foot to 0.5 foot for each hundred feet. The entire cost of draining the 72 acres of land was \$1,939.60, or \$26.94 an acre. Drainage has made it possible to raise clover on this land, and the permeability of the underdrained soil is gradually increasing

each year. The system is declared a success by the owner of the tract, who estimates that the land is now actually worth, for farming purposes, four times what it cost before being drained.

Nearly twenty-five years ago, a drain system was installed in a "white land" area on the College Farm at Corvallis, Oregon, under the direction of the late Professor French. He stated that before being drained this area was so wet that it produced little but wild oats, tar-weed, sorrel, and cat-tails. Since it was drained, its yields have steadily increased. Last season, about 5 tons to the acre of clover hay was produced on this land. The drains have paid for themselves over and over, and are more effective today than ever.



FIG. 58. Swampy area before drainage.
(Courtesy Dupont Co.)

Project No. 40 is installed near Troutdale, Oregon. The field contained 7 acres of peaty loam, too wet to farm, and producing only a marshy growth which provided a little pasture. The installation of the drain system entailed the following expenses:

Tiles, 5000 feet, 3-inch, 4-inch and 5-inch, costing. . . .	\$129.00
Freight Bill.....	12.00
Hauling of 12 loads at \$2.00 a load	24.00
Digging 306 rods at \$0.30 a rod.....	<u>91.80</u>
.....Total	\$256.80
or \$36.68 an acre	

The owner states that until the land was drained it was not worked, on account of the wet places. The drainage system was installed in 1912, and, the following winter, the main ran full for several days at a time. The next



FIG. 59. Blasting for drainage. (Courtesy Dupont Co.)



FIG. 60. Drain blasted through area shown in Fig. 58.

year, according to the owner, the piece produced \$176 worth of potatoes to the acre. In 1914, this same field threshed out 64 bushels of oats to the acre. A stand of clover has been secured which was impossible

before draining. The owner says, " We have already received full returns for our investment."

Project No. 43, an alkali area, is located in Crooked River Valley, 3 miles east of Prineville. Before this land was drained, it was regarded as practically worthless, because of the presence of black alkali in the soil. Four acres of black loam were drained with the following costs:

Tiles, 1500 feet.....	\$35.00
Freight from Portland to Redmond.....	72.00
Hauling tile to ranch.....	17.50
Labor, 7 days at \$2.....	14.00
Total.....	\$138.50
or \$34.63 an acre.....	

These figures are given by the owner, who says, " The tiles were laid 60 feet apart and 3 feet deep and drained the area easily at that distance. If placed 4 feet deep and 100 feet apart, the tiling would have drained 6 acres instead of 4. We were unable to get the latter depth owing to difficulty in securing an outlet for that level. Securing the tiles in carload lots would have reduced the expenses to \$89, or \$22.25 an acre.

" Before the land was drained, the crop in 1914 for the 4 acres was 20 bushels of barley or 5 bushels an acre. The crop in 1915 for the 4 acres was 278 bushels of wheat and barley, or 69 1/2 bushels an acre. Placing a value of \$0.80 a bushel on this crop, the result is \$222.40, which, less the cost of draining, \$138.50, equals \$83.90 net gain for the year from the above operation. From these results, we firmly believe that tile-drainage is an unqualified success. This 4-acre tract we tiled only as an experiment, and we intend to drain 40 acres more as quickly as possible. There are few investments which pay so well."

A tile system was installed on the Oregon Agricultural College Farm in the spring of 1928 which included an 18-inch main and over 4 miles of tile-lines. The excavation and back-filling for the main was contracted with the half-yard excavator (Fig. 44) at \$0.36 per foot. The Little Wonder ditcher drawn by a tractor was used to start the lateral trenches. Digging, laying to grade,

and back-filling on the laterals cost approximately \$4.00 per hundred feet. The actual cost follows:

LABOR COST — UNITS I AND II — COLLEGE FARM

1262'	18"	Digging (contract)	\$0.36 per ft	
		Laying	0.08	"
		Total	0.44	"
400'	10 and 12"	Digging (contract)	0.36	"
		Laying	0.08	"
		Total	0.44	"
912'	8"	Digging (contract)	0.26	"
		Laying	0.06	"
		Total	0.32	"
1050'	10 and 12"	Digging and Laying	0.23	"
440'	6"	Digging and Laying	0.16	"
2000'	4"	Digging and Laying	0.10	"
13600'	4" and 5" (top 20" removed with digger)		0.051	"
		Labor Cost per Manhole	7.00	
		Labor Cost per Inlet	1.00	
		Labor Cost per Outlet	3.00	

QUESTIONS

1. What are the elements that enter into the cost of a tile system?
2. What materials are used?
3. How should the tile bill be arranged?
4. Why are tiles ordered delivered and in car lots?
5. About how many tile will there be in an average carload?
6. What is a reasonable price for tile laying per man-hour?
7. Explain the effect of depth on cost of trenching.
8. Compare the cost of trenching by hand and with machine.
9. How does gravel or hard-pan affect the cost of trenching?
10. What is a reasonable percentage to allow for engineering expense?
11. Give examples of successful drainage projects.
12. Prepare an itemized estimate of cost of installing 1000 feet of 6" tile in clay loam 3 miles from your local railway station.

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CHAPTER XII

DEVELOPMENT OF WET LANDS

Reclamation of marsh lands consists of three operations: (1) construction of community outlet ditches, (2) field or farm drainage, and (3) subjugation of wild growth, removal of foreign material, and preparation of the soil for cultivation.

Feasibility of Drainage.— Whether it will pay to reclaim wet lands will depend on engineering, agricultural, and economic



FIG. 6. A large stump cracked with dynamite before pulling. (Courtesy American Society of Agricultural Engineers.)

considerations, such as the productive value of the land and the total investment therein with and without needed drainage; demand for land and farm products; the value of surrounding naturally drained upland; the size of holdings; and the community indebtedness. Transportation facilities should also be considered. Peat land offers some advantages for certain forage and truck crops which can utilize the relatively large store of nitrogen it contains. It may require some lime or mineral fertilizer, or supplemental irrigation and fire protection following drainage.

A domestic water supply should be available, and an upland building site adjacent to each tract is an advantage.

Our wet, marshy and overflowed lands offer a comparatively safe field for development. To be most successfully reclaimed, such lands should become fully settled, and be brought promptly into a good state of production, in order to avoid interest charges and facilitate the operation of tile-lines. Frequently



FIG. 62. A horse-power puller in use. (Courtesy American Society of Agricultural Engineers.)

such lands return the entire cost of reclamation with the first crop.

Time, labor, and expense are required to eliminate trees, stumps, brush, stones, tule, or even coarse peat from about 20 per cent of our wet lands. Drainage may render saw-timber or stove-wood accessible, and the sale of this material may help to pay the cost of clearing. Cutting brush in August with an axe and bush-scythe, or pasturing with goats, may be practised at times while stumps are decaying. Grass may be seeded in and the stumps allowed two to five years to decay before their removal. Stumps can then be removed by a stump-puller or engine and cable, or they may be burned by directing the fire through an auger-hole or char-pitting furnace. Dynamite, carefully used, will crack the stumps and jar dirt loose after

pulling, when stumps can be piled with a boom-pole into tall compact piles to facilitate burning.

The rank growth of tule, or swamp growth, may be subdued by carefully burning over the surface when the soil is wet, so that fire will not extend more than a few inches below the surface. This overcomes the rawness of the soil, adds some available plant-food, and tends to correct growth of moss and to help

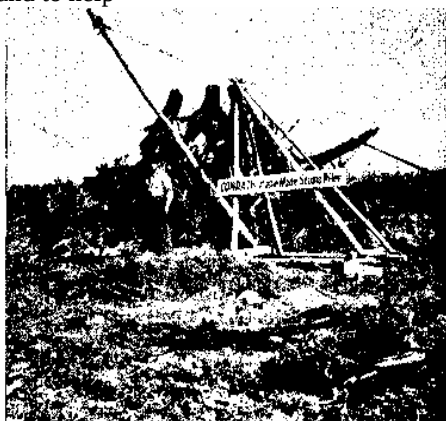


FIG. 63. A device for piling stumps. High piles burn best. (Courtesy American Society of Agricultural Engineers.)

expose roots and logs, which may need to be removed before cultivation. Open ditches for laterals will frequently be used during this process; and, as the marsh settles, more permanent underdrains may be put in. These underdrains can be extended as needed to perfect drainage, so that the more intensive crops can be grown where climate and market facilities permit.

Cultivation. — The use of a rush-cutter, or sled to which knives are attached, will aid in scalping off rushes on low lands. The rushes can then be bunched up and burned before plowing. A plow with a broad, sharp share should be used in breaking marsh sod. A 24-inch plow, drawn by a caterpillar engine, was seen in use on marsh land at the Wisconsin Experiment

Station. This outfit inverted the furrow more than in ordinary plowing, covered rubbish land firmed the soil, so as to aid decay. Thorough discing is necessary to prepare a seed-bed on new breaking. Peaty soil is loose when dry; and a compactor, such as the double corrugated roller or cultipacker, is necessary to firm the soil and bring moisture to the seed-bed. Seeding should be done early in spring. A grass mixture can be seeded and brushed in on stump land to attract stock and afford pasture while stumps decay



FIG. 64. Rush cutter.

Choice of Crops. — On peat-land, a mixture of Alsike clover and timothy has been successfully seeded into the ashes after marsh vegetation has been burned. Feeding out clover hay on the land without plowing up



FIG. 65. CRANBERRIES GROWING ON
SPHAGNUM PEAT LAND

has established Alsike in some marsh meadows. A fairly permanent meadow can be established on low, wet areas by using a mixture of grasses such as blue-grass, English ryegrass, timothy, redtop, and white or Alsike clover.

On better located areas, after the first breaking rank feeding crops like oats, barley, flax, or corn should be grown for a year or two; then, if the water-table is at sufficient depth, the Alsike clover should do well. Canary-grass and bent-grass make excellent pasture, and have been used on the peat lands near the Pacific Coast.

When sod-bound meadows are harrowed after several years, they may be re-plowed and used for a couple of years for grain and row crops, such as roots, then seeded down again.



Fig. 66. Truck garden on drained tide land at Astoria Oregon.



FIG. 67. Splendid crop of onions grown on reclaimed willow-sedge peat near Salem, Oregon.

Thoroughly drained and subdued neutral peat land, where located within reach of markets, is used for potatoes, celery, onions, roots, and other leafy truck-crops which thrive on soils rich in nitrogen. The cranberry is also produced in certain localities on acid peat land.

Fertility in Marsh Soils.— Peaty soils are apt to be raw when first drained, and may respond to manure or complete fertilizer. When subdued, these lands usually have an abundance of nitrogen and humus, but frequently respond to applications of potash. Fertilizer trials on muck soils in different sections of Oregon have not shown much benefit from the use of potash; but super phosphate and manure have frequently caused increased yields. Potash is more likely to benefit deep peat that has received little inorganic material by in-wash from adjacent uplands. In some cases a little copper or manganese increases yields.

Treatment of Heavy

Land. — Experiments are under way to determine the best treatment for " white land " on the Oregon Experiment Station farm. The whole field is seeded to one crop each year and a three-year rotation is employed; viz., spring barley, followed

by clover, one crop a year, then a cultivated crop, such as corn. The effect of lime, manure, green manure, and combinations of these treatments is tried out on duplicate plots, and their value is judged by the use of check-plots.

In a new experiment field, straw and gravel are being compared as to their cost and effectiveness in helping the water to enter the tile drains. The results with each material are being measured and judged by the comparative yield and the relative amount of runoff.

Operations that Aid Drainage. — From studies already made, it appears that the following things can be done to aid under-drains in collecting water in " white land " or other retentive soil:

- (1) In draining a retentive, saucer-like area, the protecting drains should be laid out so as to collect seepage-water or surface-water before it reaches the retentive soil.



FIG. 68. Celery grown on reclaimed peat land in Lake Labish Drainage District, Oregon.

- (2) Catch-basins should be used in the upper side of the field, or at points where the surface-water is apt to run on to the heavier soil.
- (3) After the tiles have been laid and blinded, the trench should be allowed to remain open a few weeks, where the dry season permits, so that air can come into contact with the subsoil and cause it to slack and crumble.
- (4) In filling the trench, it is advisable to put in sod or straw, and then the top soil immediately over the tiles. Straw will decay, thereby increasing the open space whereas gravel may silt up. However, where the grade is steep, gravel would protect the tile from washing out better than straw. If the sticky, sub-surface soil is used, it must be put in the top of the trench.
- (5) When it is dry enough to crumble, the land should be plowed deeply.
- (6) After the installation of drainage, lime will become more effective and will aid in mellowing the soil.
- (7) Drainage and liming will, in most cases, make it possible to raise clover on the land. Clover roots will penetrate the drained soil and will be of great value in loosening up valley land so that water can pass through and get into the drains.
- (8) Where possible, the land should be plowed in such a way that the dead furrows will fall directly over and parallel to the laterals, giving the surface a slight slope toward the laterals. Surface-water that collects in these dead furrows will pass into the laterals more readily. If it remains on the surface temporarily, and there is ample tile capacity, occasional catch-basins can be provided on heavy soil to aid in sending water into the drains underneath.

Clover should be grown on the heavy land about each third year in rotation with grain and cultivated crops or other similar crops. A decidedly larger relative outflow has been observed in the wet season following a clover crop, and water has disappeared more rapidly. With manure and clover plowed under,

one in each rotation, the yields of these crops on tiled land can be built up to compare very favorably with the best uplands.

Treatment for Alkali Lands. — Alkali land, after being drained, can be improved, where nearly pure water is available, by irrigation, after treatment with sulphur or sulphates. One or more seasons of irrigation will usually be required to remove and disperse alkali to such an extent that, by deep plowing, hardy crops, such as rye or sweet clover, can be established. It may take from one to three years to complete the reclamation of these lands, depending upon the amount of alkali and the retentiveness of the soil. Such crops as rye or sweet clover, if plowed under, will supply humus and nitrogen and loosen up the soil so that moisture conditions may be more readily controlled. During the process they may provide some return in the form of pasturage. The alkali lands, when thoroughly reclaimed, are usually strong in the mineral plant-foods and suitable for alfalfa and the other staple crops of the region. A more complete discussion of this problem will appear in Chapter XX.

Care of Tile Systems. — Outlets, channels, silt-basins, and inlets should be inspected and cleaned, if necessary, before the season of heavy precipitation and after heavy storms. Any obstructions in tile-lines should be located and promptly removed. The land should be watched and tile-lines extended, if necessary, till the system serves the entire wet area.

The treatments above described are calculated to assist in loosening up and aerating the drained soils and to assist water in entering the drains provided. The legumes and manuring crops suggested will also supply humus and nitrogen, which are ingredients none too plentiful in much of the "white land" and irrigated and alkali land. This treatment would pave the way for cash crops and make it possible to get the greatest possible benefit out of the drains installed, and so render the enterprise thoroughly successful and profitable.

Land Settlement. — Drainage often makes closer settlement possible or desirable by rendering a smaller acreage sufficient for the adequate support of a family. A land settlement program may well include (a) selection of settlers having at least a

fair amount of capital and agricultural experience; (b) furnishing them with authentic information, such as soil and economic surveys afford; (c) a local committee or impartial advisor to guide them into suitable agricultural enterprises; (d) cooperative marketing facilities; (e) control of land speculation and (f) adequate credit facilities with reasonable interest rates.

Holland's experience in drainage has led to complete reclamation before settlement is undertaken. A system of interior drains, waterways, and hard roads is provided by utilizing canals and dikes to provide transportation for every farm unit. Careful planning reduces to a minimum the area in waterways and the number of locks or bridges required. The reclaimed land is divided into 50-acre units (880 by 275 yards), which may be doubled for the maximum general farm area, or divided for intense use in vegetable gardening or bulb-growers' tracts. A hard road serves one end, and a navigable drain the other end of the farm unit.

QUESTIONS

1. What three operations are included in reclamation of marsh land?
2. How can rank tule growth be removed without serious injury to the soil?
3. How may rushes or tussocks be killed out and removed?
4. What machinery is suitable for breaking and firming marsh land?
5. What crops are suitable for newly broken marsh land?
6. What legumes and grasses are adapted to reclaimed marsh land?
7. In what proportion are the important plant-food elements present in peaty soil?
8. What fertilizers are most likely to benefit swamp soils?
9. What treatments will aid percolation into tile in heavy drained soils?
10. Outline a land settlement program.
11. What factors determine feasibility of drain age?
12. What treatments will aid in restoration of structure and productiveness of tiled alkali soil?
13. What precautions should be taken to maintain tile systems after installation?
14. Give the essential features of a land settlement plan.

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PART II. —DISTRICT DRAINAGE

CHAPTER XIII

DRAINAGE DISTRICTS AND DRAINAGE LAWS

The greatest obstacle encountered in draining large areas of nearly flat-lying land is the lack of an outlet for the individual farm. In these areas, a community interest is imposed by nature upon the landowners. To secure a community outlet ditch, where many owners are concerned, it is necessary to organize by law a practical drainage district.

Drainage laws like others come from enactments of state legislatures, or from recognition in court decisions of common law practices and customs. The rights of the individual will first be considered.

Common Law vs. Civil Law.— Some states have adopted the English common law rule or common enemy rule, the fundamental principle of which is that a landowner may lawfully protect his land from the surface water flowing upon it from adjoining higher land. Under a strict interpretation of this rule, the owner of higher lands may not improve the natural water course on his own land to the injury of a lower-lying neighboring tract, unless he secures an easement from his neighbor.

Other states have adopted the civil law rule from the Roman law, which is to the effect that the owner of higher land, known as the dominant owner, is entitled to any natural drainage, and that the lower or servient owner must receive water flowing from higher land through natural depressions. The dominant owner may improve the channel on his own land but not upon the land of the servient owner against the will of the latter. The common law and civil law states are:

Common Law States

Arkansas
Connecticut
Indiana
Kansas
Maine
Massachusetts
Minnesota
Missouri
Nebraska
New Hampshire
New Jersey
New Mexico
New York
Oklahoma
South Carolina
Virginia
Washington
Wisconsin

Civil Law States

Alabama
California
Georgia
Illinois
Iowa
Kentucky
Louisiana
Maryland
Michigan
North Carolina
Ohio
Pennsylvania
Texas

Drainage District Laws— The object of drainage district laws is to make possible the construction of outlet drains for the community, through cooperation of the owners benefited, and to meet the cost by equitable assessment. The ultimate object is to fit the land for more profitable production. The district law prescribes a definite method of procedure whereby communities can organize, under proper governmental authority, to drain for the public welfare, issue bonds, and assess costs.

Fundamental Principles— The principles involved in the undertaking are as follows: (1) It must be cooperative and optional. (2) It must be for the public welfare. (3) Assessments must be adjusted in proportion to benefits. The benefits should be more than the cost, *including* damage and overhead expense of the district, legal expenses and an amount which will earn sufficient interest to cover the cost of maintenance. That is, benefits must be sufficiently in excess of costs to pro-vide a maintenance fund. (4) The right of way must be paid for. (5) The owner should have the right of appeal, if necessary, to secure equitable assessments. (6) The right of outlet

should be perpetual and should be attached to the land title. (7) The drainage tax should be a first lien on the land.

Such a law, to be successful, must, of course, conform to the laws of the state. The assessors should not be related to the owners by blood or marriage; the benefits should be more than cost plus damage; the bonding should be decided upon by the drainage commissioners or owners of the land in the district. A drainage district may issue and sell securities or bonds against the lands included for the purpose of borrowing money at moderate interest rates for a long period of years, during which time the increase in crop yields will enable the landowner to pay off the loan in moderate installments.

Drainage Laws of Different States— The first practical district drainage law was enacted by Illinois, and this was followed by similar laws in other Corn Belt States. The laws were improved by amendment from time to time, until they became complicated. The National Drainage Congress appointed a commission to draft a uniform and model district drainage law in 1912. The modern law drawn up by this commission was promptly adopted by the State of Missouri, where drainage bonds are said to have since sold at or above par. Partly through the efforts of the State Agricultural College, the State Engineer's Office, and the State Drainage Association, a drainage law patterned after the model drainage law, refitted to Oregon conditions, was passed by the Oregon legislature and became effective May 22, 1915. This law was recommended by the leading drainage authorities in the United States. It has recently stood the test of the United States Supreme Court. Some preliminary survey work is necessary before a petition for a district can be prepared. A map showing the individual ownerships, chief roads, general topography, texture of wet areas, and plan of drainage, should be prepared. The successive steps necessary to secure outlet ditches under such a law are shown diagram-matically in Fig. 69. The principal features of the law are as follows:

- (1) The owners of 50 per cent or more of the acreage in the proposed district must petition the county court, which has

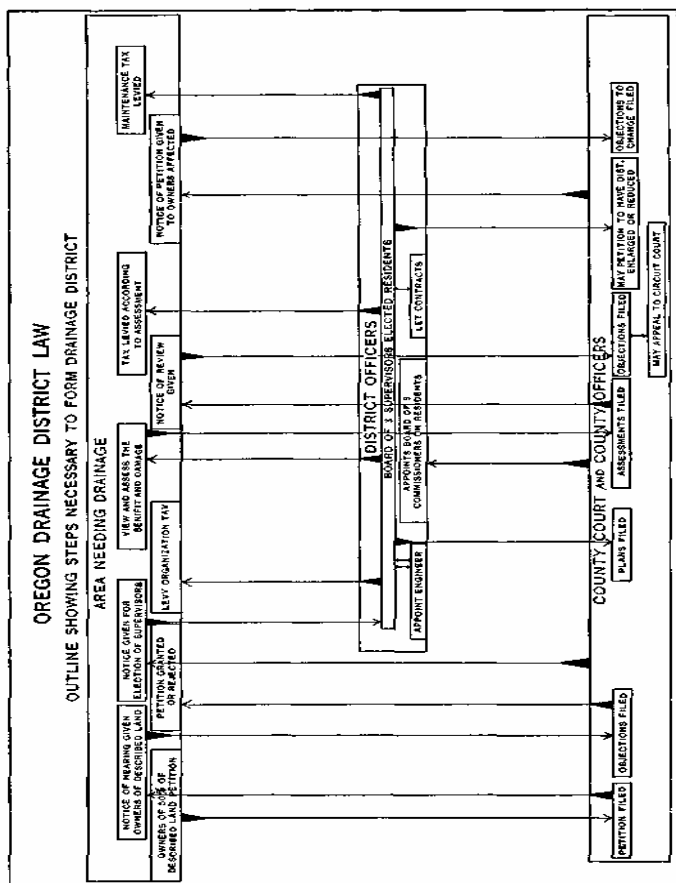


FIG. 69. Diagram illustrating procedure under the Oregon District law.

general supervision of drainage districts, for the organization of a district. The petition must contain:

- (a) the name of the district;
- (b) the boundary lines of the district, or description of all the lands constituting the wet areas;
- (c) the total acreage;
- (d) the names of landowners within the district as shown by the county records;
- (e) an allegation that the proposed drainage project is for sanitary or agricultural purposes and of public benefit;
- (f) an allegation that the lands included are properly included and will be benefited;
- (g) an allegation that benefits will exceed damages; (h) an allegation that the district plan is a proper method of accomplishing reclamation;
- (h) a brief statement of the plan of reclamation;
- (j) an agreement that signers will share in all expenses of organization or pay cost of attempted organization if not established;
- (k) a petition asking that the lands be organized.

The petition must be verified by affidavit. It must state the general plan of reclamation and give authoritative evidence that the drainage proposed is regarded as feasible.

(2) A formal notice of petition and of hearing must be sent by the county clerk to all the landowners. The county court considers the petition and any objections filed and will establish the district or dismiss the petition.

(3) After approval of the petition, the county clerk calls a meeting of the landowners for the purpose of electing a board of three supervisors, who must be landowners in the proposed district, to have general charge of the enterprise, and to hold office as determined by lot from one to three years or until their successors are elected and qualified.

(4) The board elected has power to appoint a drainage engineer and to levy a tax of not more than \$1.00 per acre on the holdings of those who signed the petition, for the purpose of

paying expenses incurred or to be incurred in organizing the proposed district. The board files with the county clerk a plan of reclamation prepared by the engineer, and may petition the county court to alter the boundaries of the district. The board is required to keep a record of its proceedings.

(5) The county court appoints three commissioners who are disinterested persons to make the assessments of benefits and damages and file a report with the county clerk.

(6) Property owners are notified of this report by publication and may file objections with the county court.

(7) The drainage board must levy the assessments, let contracts, and secure the construction of all drainage work; they may issue bonds and collect the assessments in annual installments. They may also levy a maintenance tax and define terms whereby existing drains may be connected with the ditches in the district. A detailed estimate must be prepared before active construction can begin. Benefits should exceed costs, and costs should include damages, construction, engineering, and legal services.

Laws of the various states differ in several particulars, including the following:

- (1) The proportion of acreage of owners who must petition
- (2) The manner of excluding lands from the district
- (3) The number of directors
- (4) Whether vote is by acreage or by individuals
- (5) The provision for governmental supervision

The new Oregon law places the important work in the hands of the landowners who are directly interested. It is believed by good attorneys that this model law will be found adequate and clear in methods of organization, administration, and maintenance of reclamation districts. There are over two dozen drainage districts already organized under this law; in several of these the work has been carried to successful completion, and thus far the law has proved thoroughly practical. Drainage districts organized under similar district laws have effected a wonderful transformation in much of the Corn Belt. District drainage will make it possible to double the productiveness

of much of the 95,000,000 acres of wet land in the United States.

Mutual Districts. — The drainage laws enacted by the legislature of a number of states provide for organization of mutual consent drainage districts. An agreement is drawn up and signed describing the work to be done and showing the division of cost, and is acknowledged and filed. All signers may act as a drainage committee, or a committee may be designated with power to act in carrying through the plans. A mutual district saves time and organization expense, yet, because it is difficult to get several landowners to agree on a plan and division of the cost, this law is generally applicable to small areas only.

Some states have a state diking district law which has proved to be simple and practical for small projects. Wisconsin has a township ditch law which is said to be simple and practical for small community drainage enterprises.

Joint Drains. — Where two adjoining owners are concerned in a drainage system, a common arrangement is for the upper landowner to pay for the difference in size of tile across the lower owner's land so as to secure underground outlet capacity for his land. Right of way can usually be secured by arbitration and assessments of benefits and damages, or by condemnation if arbitration fails. Drains are commonly given the privilege of eminent domain.

DRAINAGE DISTRICT PROCEDURE

The Tillamook Drainage District. — The Tillamook district was the first to be organized under the Oregon law of 1915, and, since it has been carried to completion, this district project is used herein as an example. At the request of persons interested, through their county agriculturist, the major author, accompanied by an engineer of the United States Office of Drainage Investigations, made a preliminary examination of the district, May 15, 1915. The tract a mile or so wide and a mile and a half long, shown in Fig. 70, is located just south of the city of Tilla-mook, Oregon, and includes a marshy area too wet to afford

much pasture. The soil below the tenth contour is peaty muck underlain with blue clay at 5 or 6 feet. Silt loam covers the remainder of the bottom land, while a gravelly loam extends over the bench. The rainfall is perhaps 75 inches a year. Preliminary levels and soil examinations were made to determine the feasibility of the drainage, and a canvass was

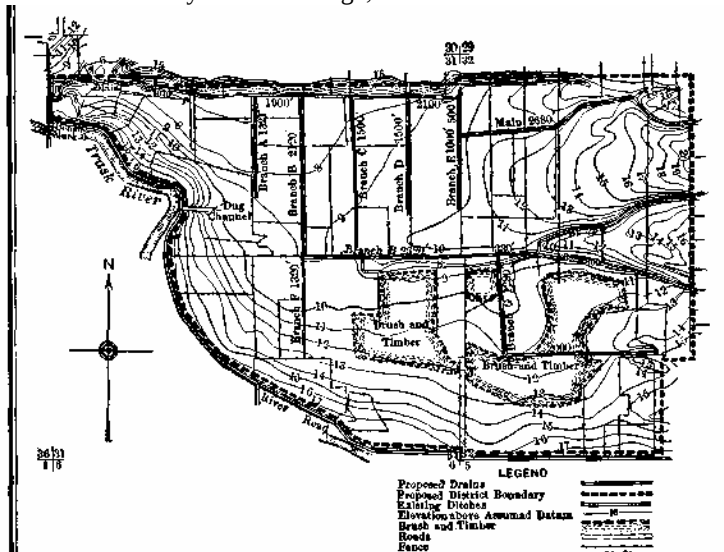


FIG. 70. Map of Tillamook Drainage District, Oregon.

carried out to determine the sentiment of owners in regard to the organization of the district. Very little opposition was encountered; and, as the soil and topographic conditions were favorable, a petition for organization of a drainage district was prepared.

Organization. — The prepared petition and notice of hearing are presented herewith, to give a definite idea of procedure under the 1915 law. The petition is required to be published as a part of the notice.

"NOTICE OF HEARING PETITION TO FORM DRAINAGE DISTRICT"
IN THE COUNTY COURT OF THE STATE OF OREGON, FOR THE COUNTY OF
TILLAMOOK

Notice is hereby given that hearing on the following petition will be held at the Court House in the City of Tillamook, County of Tillamook, State of Oregon, on the 16th day of July, 1915, for the purpose of determining whether the prayer of said petition shall be granted.

All persons owning or claiming an interest in lands described in said petition are hereby notified to appear at said place and on said date if prayer in said petition should not be granted.

(Signed)

CLERK OF COUNTY COURT .

PETITION

To THE HONORABLE COUNTY COURT OF TILLAMOOK COUNTY, STATE OF OREGON.

The undersigned, being owners of more than fifty per cent of the acreage of the contiguous body of swamp, wet, and overflow land in Tillamook County, Oregon, hereinafter described, do hereby petition your Honorable Body to cause to be organized a drainage district for the purpose of having such lands reclaimed and protected from the effects of water, for sanitary and agricultural purposes and for the convenience and welfare of the public, utility, and benefit; and for the purpose of this petition we state the following matters as required by Chapter 340 of the General Laws of Oregon, for the year 1915:

I. The name proposed for such district is " Tillamook Drainage District."

II. The boundary lines of the proposed district are as follows: *(Here followed description of boundaries by legal subdivisions.)*

III. The total acreage included in the said proposed district is 555 acres.

IV. The names of the owners of the land in said proposed district, as shown by the records of Tillamook County, Oregon, and the acreage owned by each of said owners is as follows:

(Here followed names of twenty-two owners concerned, and acreage owned by each.)

V. The proposed reclamation and protection of said lands is for sanitary and agricultural purposes; and such proposed reclamation and protection will be conducive to the public health and welfare, and of public utility and benefit.

VI. All of the lands included in said proposed district are properly included therein, and will be beneficially affected by the operations of the proposed district.

VII. The benefits of such proposed reclamation and protection will exceed the damage to be done; and the best interest of the land included, and of the owners of such land as a whole, and of the public at large, will be promoted by the formation and proposed operation of said district.

VIII. The formation of a drainage district under the provisions of Chapter 340 of the General Laws of Oregon for 1915, under the provisions of which this petition is proposed, is a proper and advantageous method of accomplishing the reclamation and protection of the land in said proposed drainage district.

IX. The proposed plan for the reclamation and protection of the property in the proposed district is, that a ditch shall be put in, running from the west side of the proposed district (connecting with a ditch running along the west side of the district which empties into the Trask River), easterly along the foot of the hill which is along the north side of the district, following the line of the ditch already partially constructed in that locality to the east side of the district. Also there is to be constructed another ditch connecting with the ditch above mentioned, running south on the west line of the east half of the northwest quarter of the Section 31, in Township 1 South, Range 9 West to the quarter section line running east and west through said Section and running thence east along the quarter section line to the east line of the proposed district or so far as may be found

necessary for the drainage purposes in this section. The two ditches are to be the main ditches for the drainage proposed, and they are to be constructed with such laterals as may be found necessary to make the drainage effectual. The land included in the proposed district is so situated that, without ditches being constructed, the water is not drained off, and the land remains cold and sour. There is a fall of about 25 feet from the east side of the district to the west side thereof, and it is believed that with the construction of the ditch as proposed the water will be drained off from all of the lands so that they will dry much more rapidly, and the same will be in proper condition for cultivation, and much more productive.

X. The signers of this petition agree that they will pay any and all expenses incurred, and any tax or taxes that may be levied against their respective lands for the purpose of paying the expense of organizing or attempting to organize the proposed district, such expense to be taxed against the lands of the signers in proportion to the number of acres owned by them and affected by the proposed drainage.

XI. Wherefore, your petitioners pray that the lands described herein, or such of them as may be found by the court to be properly included in the proposed drainage district, either permanently or until further investigation and surveys may permit elimination, shall be declared organized into a drainage district under the provision of Chapter 340 of the General Laws of Oregon for the year 1915.

Dated this May 28th, 1915

(Here followed signatures of owners)

STATE OF OREGON

COUNTY OF TILLAMOOK

I, -----, being first duly sworn, say that I have read the foregoing petition and that I believe the allegations thereof to be true. I further state that the signatures appended to said petition are true and proper signatures of persons whose names appear signed thereto, and that each and all of said signers of said petition are owners of the land

within the proposed drainage district as set forth in said petition.

Notary

Subscribed and sworn to before me this 2nd day of June, 1915.

County Clerk

First publication June 3rd, 1915.

Last publication July 1, 1915.

In June, the government engineer returned and made the field survey, with assistance furnished by the district, and prepared the plan of reclamation indicated on the accompanying map of the district. Poor drainage and the shallow water-table were due to lack of outlet. The present purpose of the new drains is to remove the flood-water quickly in the spring, and supply outlets to the individual tracts. The main ditch and the several laterals were laid out with a mean depth of about 6 feet. Construction work was completed the same season, and the crop increase the following year was worth more than the entire drainage cost.

QUESTIONS

1. What is the purpose of a drainage district law?
2. Upon what principle is a drainage district law based?
3. What portion of the acreage must be signed up before filing any drainage district petition in Oregon?
4. What things must this petition contain under the model district law?
5. How are the drainage district officers selected, and what are their duties?
6. Who appoints commissioners to assess benefits and damages, and what qualifications must these assessors possess?
7. What are the chief differences in the district drainage laws of different states?
8. Give an example of the method of procedure and results under district drainage.
9. What are the different theories as to the drainage rights of two neighboring landowners on a drainage course?
10. What is a mutual consent drainage district and how is it handled?

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CHAPTER XIV

ASSESSMENT OF DRAINAGE BENEFITS AND COSTS

It is of fundamental importance in a drainage district that the assessment be in proportion to the benefits, so that each may pay only for the drainage he gets. The benefits may be classed as special and agricultural. Special benefits include benefits to highways, railways, power lines, town lots, or outlets to factories. Agricultural benefits are increases in value of land, due to greater productiveness, accessibility, and decreased cost of agricultural operations. Increase in productive and speculative values should both be considered. Construction and operation of an outlet ditch helps to consolidate and develop the community through general improvement in accessibility and healthfulness. Damages are assessed separately and allowance made therefore. Laws of most states stipulate that the benefits must exceed organization and construction costs, plus damages, in order to be of community benefit and secure court approval.

Assessment of Damages. — The commissioners appointed to appraise benefits may in some states assess damages; but these are usually carried separately, the two not being allowed to offset each other. In allowing damages for an open ditch-way across a field, the additional ditch-way needed may be actually bought. Sometimes a bridge is built for the owner or its cost allowed and the owner authorized to build it. Building the ditch may spoil a watering place for stock, and damages may be allowed to the amount of a well and pump, or a stock ford may be authorized and its cost allowed for. Damages are sometimes claimed by owners farther down the creek; but in dozens of cases the results show that floods are lower after drainage, because the drained area constitutes a reservoir of dry soil which absorbs the rain and equalizes the runoff. Small parcels of land cut

off by the ditch so as to be of little use are paid for by the district.

Highways are allowed damages where district ditch crossings are constructed with road funds. Railways may be allowed damages equal to the difference in the value of old bridges and new ones required for the outlet ditch crossings.

Special Benefits. — Special benefits from drainage are assessed against railroads, highways, power lines, town lots, and factories. Where a highway is benefited, a share of the drainage tax should be assessed against the road funds. The same is true as to railroads where drainage lessens floods and decreases the maintenance cost. If before drainage the track was occasionally flooded, and drainage lowers the high-water mark to 3 feet below the rails, then the benefit can be estimated on the basis of the amount of fill that would have been required to accomplish this. The drainage tax may amount to any fraction of the benefits, but the proportion for special benefits must not exceed the proportion for benefits to agricultural land. City lots may receive special benefits, which may run as high for a lot as for an acre of agricultural land. Creameries may agree to pay certain amounts for sewage outlet privileges.

Principles Underlying Assessment of Benefits.— Laws of most humid states stipulate that assessment of costs shall be in proportion to benefits. This theory is based on the consent of the majority of owners to pay for what drainage they get. Assessments for drainage in irrigated lands of arid sections are often made on a flat rate per acre. This theory is based on the idea that the owners of higher-lying lands or irrigation canals are responsible for water they divert from the natural water courses and should help take care of their seepage or waste. Such assessments are levied as a police duty of the municipality. The supreme court of Oregon and the state legislature have upheld the idea of assessing contributing damages or charges against such higher-lying property. Proponents of this theory argue that it is impossible to predict when the lands located in higher parts of a project may come to need drainage as the irrigated area is extended.

Harmon and others have advocated that part of the cost be collected as an *ad valorem assessment*, because of inaccessibility and slower development of heaviest " benefited " lands during the first years after drainage. Accessibility is of greater importance now when motor transport and auto travel are so general.

Laws of most states provide for assessments according to benefits. This seems to be the broader principle, as it permits use of a flat rate where all the land is similarly benefited, as within a meandered marsh. However, in applying to an arid country a law devised for a humid one, we are apt to find it a misfit, and *vice versa*.

The following considerations should be kept in mind in assessing benefits and costs under the humid drainage laws.

- (1) The owner is entitled to the natural drainage his land possesses; but if the district system cuts off water from land above him, the benefit of this intercepting drainage should be assessed according to the improvement it makes in the condition of his land. This would apply also to an owner on whose land the natural outlet for the district is located.
- (2) Topography is a leading consideration, for the purpose of the district is to provide outlets for field drains where the fields have been too flat for tiling out at a good depth.
- (3) The distance from the natural outlet is a factor in some states, as the drainage ditch provides for the distant land the benefits which the land close to the outlet already in a measure had.
- (4) Assessments are less where only partial drainage is provided, as in the case of land located farther back from the drainage ditch or near the shallowest portion of the ditch.
- (5) Land of high fertility and good drainage properties should be assessed more than that of lower quality because the value of the drainage is greater.
- (6) Crop adaptation and climatic conditions should be considered in estimating benefits.

Methods of Assessing Benefits.— Commissioners should walk over every 40-acre tract, accompanied by the project engineer, and classify lands with great care. The commissioners usually choose their own scheme for levying assessments. On marsh or arid land, the agricultural taxes may be on a flat rate. Where assessment of benefits is required in apportioning costs the land is usually classified, and a value estimated for the area of each tract belonging to each class before and after drainage. It is sometimes assumed that the drainage is a public benefit and the main consideration is given to existing value of property as in other property taxes. Sometimes classes of benefits are established for different areas and in other cases lands are classified and assessed according to percentage of benefit.

In classifying land for drainage taxes, probably the simplest method is dividing the land into classes and then rating the very wet or marsh acres at 100 drainage points an acre. The wet agricultural land will be rated at a lower number of points an acre, and only a few points an acre will be levied against land already tillable. The number of acres in each class is then multiplied by the number of drainage points assessed against it, to get the total number of units of agricultural tax. After deduction of special assessments from the total estimated cost, the balance is divided by the total number of units as obtained above, to get the tax per unit. The assessment list of the Tillamook Drainage District is again referred to for an illustration of this method of assessment.

Other methods of assessment used are: a basis of increased land values, and a percentage basis.

TABLE XXIII.— ASSESSMENT LIST OF THE TILLAMOOK DRAINAGE DISTRICT, STATING THE BENEFITS

Owner	Acres Assessed	Points of Drainage Assessed per Acre		Total Points of Drainage	Total Acres
No.					
1	10.33	100	1033		
1	28.33	5	141.65		
1	21	9	189		
1	40.34	100	<u>4034</u>	5397.65	106.63
2	100	100		10000.	110
3	62	100		6200	80
4	22	100		2200	27.51
5	10	100		1000	12
6	5	100		500	6.28
7	5	100		500	5.
8	2.5	100		250	2.5
9	8	100	800		
9	6	100	600		
9	13.51	50	<u>675.5</u>	2075.5	27.51
10	8.5	67		569.5	33.58
11	9	52		468	46.28
12	9	52		468	37.52
13	12	52		624	30
14	34	100		3400	40
15	5	90		450	44
16	60	100		6000	76
17	12	100		<u>1200</u>	<u>14</u>
				41302.65	698.81

Benefits of the old ditch which was appropriated by the Tilla-mook Drainage District, to be refunded as follows by the Tilla-mook Drainage District.

No. 1.....	\$160.00
“ 2.....	140.50
“ 4.....	25.00
“ 16.....	25.00
“ 3.....	113.00

Clerk
Commissioner
Commissioner
Commissioner

Subscribed and sworn to before me this 13th day of Dec., 1915

County Clerk

Where the law requires benefits to be fixed, the following form is suitable.

TABLE XXIV.—ASSESSMENT OF TAXES ACCORDING
TO BENEFITS

P ar ce l	Acres		Apportionment of Cost Dollars					Addition and Subtraction		Tax Dollars	Benefits Dollars
No.	Benefited	Not Benefited	Main Ditch	Lateral	Small Tile	Oregon Irrigation	Total	Reason	Amount		
1	40	.0	400	0	2000	80	2480		+80	2560	5120
2	40	0	400	0	0	80	480	Deep Peat	-80	400	800
3	40		200	240	2000	80	2520		+80	2600	5200
4	40	0	160	240	0	80	480	Heavy Clearing	-80	380	760
5	40	0	0	240	2000	80	2320		+80	2400	4800
6	40	0	400	0	0	80	480	Ditch dug 4 feet deep	-200	280	560
7	15	5	160	1000	0	30	1190		+30	1220	2420

The above form, suggested by E. R. Jones, is convenient for making assessments where the law requires benefit to be fixed in arriving at drainage district taxes.

In the Tillamook district there were 698.81 acres, and each acre was assessed the number of drainage points corresponding to the amount of benefit. The total of drainage points as shown by the assessment list for the district was 41,302.65. These were assessed 5 cents a point, raising \$2,065.13. The total cost of securing the outlet drain amounted to \$1,612.57, leaving a balance of \$452.56 to be used for maintenance.

Distribution of Costs.— The various items of expense were as follows:

Attorney fees for drafting petition	\$50.00
Engineer and helpers (prelim, work by U. S. D. A. Eng.).	38.19
Advertising.....	50.00
Excavating new ditch and repairing old ditch.....	990.88
Old ditch used by drainage district	463.50
Three commissioners, one day	15.00
Clerk, one day.....	5.00
Total.....	\$1612.57

The construction work was carried to successful completion in the summer and fall of 1915.

Results. — The secretary of the Tillamook Drainage District writes that they have found the new law adequate and practical, while the increased yields have returned at least half the total cost of the district during the first year. As the cost was only about \$3 an acre, the expense was handled on a cash basis without issuing bonds. Since the outlets have been provided, several owners in the district have completed their field drainage by supplementary underdrains.

Drainage District Bonds. — The model district drainage law provides that bonds may be issued to distribute the expense of providing outlet ditches over a period of twenty years, during which time the increase in yield from drainage should be abundant to provide profits for retiring the bonds. The distribution of bond payments is shown for a \$6 annual tax table.

TABLE XXV. — ANNUAL PAYMENTS ON A 6 PER CENT
FIVE TO TWENTY YEAR DRAINAGE BOND, WHEN
ASSESSED AT \$6.00 AN ACRE

Years	Prin. Maturities	Interest	Prin.	Total Amount Payment
1		.36		.36
2		.36		.36
3		.36		.36
4		.36		.36
5		.36	.40	.76
6	.40	.336	.40	.736
7	.40	.312	.40	.712
8	.40	.288	.40	.688
9	.40	.264	.40	.664
10	.40	.240	.40	.640
11	.40	.216	.40	.616
12	.40	.192	.40	.592
13	.40	.168	.40	.568
14	.40	.144	.40	.544
15	.40	.120	.40	.520
16	.40	.096	.40	.496
17	.40	.072	.40	.472
18	.40	.048	.40	.448
19	.40	.024	.40	.424
20	<u>.40</u>			
	\$6.00	\$4.311	\$6.00	\$10.311

When assessed at \$12 an acre, the above figures would be doubled.

This allows five years to get the newly drained land into going condition before principal payments begin. The maximum annual payment on an acre assessed at \$6 would be 76 cents.

Several districts organized in Oregon have issued bonds and have found a ready sale for them. Good bond attorneys state that the law provides for a good bond. In the central states, drainage district bonds are regarded as good investments and, in places, sell above par. It is important that the law be carefully followed if this is to be the case. Drainage district bonds are said to be most attractive where the land in the district is owned by those who live on the land and develop it, rather than where land is held for colonization purposes under corporate

ownership. Usually the total amount of bonds is small in proportion to the aggregate appraised value of land in a drainage district; but it is well to get practical assurance that the benefits will exceed the total cost of drainage. The total indebtedness of the district for all purposes, including drainage, should not be allowed to become burdensome. The short community ditches in many sections can be paid for on a cash basis without bonds, if a rural credits measure or the federal farm loan act provides money at moderate interest rates.

State Aid.—A measure enacted in Oregon provided for state guarantee of interest for from one to five years on bonds of feasible, approved drainage districts. The law required that the project must be carefully investigated at the expense of the district, and must be found feasible in several particulars and "for the best interests of the district and the State "before the project could receive certification. Certification was placed in the hands of a State Reclamation Commission. The bill gave preferential entry right to persons who had been engaged in military service. In case the state advances any interest, it is to be returned later when the project is in a going condition.

As recently amended, the State Commission may waive repayment of any portion of the interest advanced after agreement has been reached with bond holders to reduce repayments correspondingly. The state is declared free of liability as to the principal.

In some states, Drainage Commissioners may make a limited levy for interior road improvements, and cooperate with the county courts in the work.

Project Feasibility Surveys.— In localities where there are a number of drainage problems to be met, the state or federal experiment stations make a practice of sending a field man to make examinations and to give a demonstration or advise the community as to the means of securing drainage. Field work usually consists of subsoil and water-table examinations and the taking of some preliminary levels, to determine the available fall or best possible outlet and the location and design of drains

required. Where there are several days of surveying to be done, it will usually be necessary to secure services of a professional engineer. This preliminary work aims only to aid drainage enterprises in getting started right without competing with private enterprise. Arrangement can often be made with the U. S. Office of Drainage Investigations to cooperate in securing some preliminary data in sections where the practice of drainage is entirely new. These investigations aim to determine the feasibility of the proposed drainage project from an engineering and agricultural standpoint. The result of such preliminary investigation will be the organization and development of feasible projects. To carry these projects through, a good attorney and a drainage engineer should be employed, for it will pay to have the work done right. The states could well afford to carry on more extensive investigations of the effect of underdrains in the marshy, alkaline, wet clay, and other wet lands. Such feasibility surveys help in developing a rational system of water laws.

Refinancing.— Reclamationists of different states have much in common, and drainage interests have much in common with irrigation interests. If land becomes water-logged and alkali-ed and so goes out of use, there is a loss in value which adds a burden to adjacent irrigated land. Within some irrigated projects in the Northwest there are many drainage enterprises. Frequently, drainage will develop water needed for supplemental irrigation, especially where pumping is employed.

Reclamation is more than the day's work. We build for the future. A distribution of the construction costs over a number of decades seems reasonable.

Various refinancing proposals have been suggested as a solution for financial problems confronting established, meritorious reclamation districts.

Reclamationists, in recent years, have been considering: —

- (a) A national program for the refinancing of established, meritorious irrigation and drainage districts where there is need of it, and with a federal fund administered through a government agency. This has seemed more timely than new construction.

- (b) It is thought that this fund might reasonably carry not over 3 per cent interest plus 1 per cent for amortization of the principal during a period of approximately 40 years. A lower rate has been charged to European nations by our government than is proposed herein for the relief of settlers who are pioneering the development of our reclamation projects.
- (c) It is proposed to loan for this refinancing on a basis of productive value to be determined by investigations to be made and paid for outright by federal and state agencies.
- (d) It is suggested that use be made of the experience and information embraced in the U. S. Reclamation Bureau and the U. S. Division of Agricultural Engineering.

Federal aid should be conditioned upon:

- 1. A detailed soil and economic survey.
- 2. The economic soundness and large scope of the enterprise.
- 3. The liquidation of existing debt and refinancing on productive value.
- 4. Outright payment for investigations.

Such a plan has been endorsed by the National Drainage Association, and by the National Water Users Congress. Suggestions have been made to:

- (a) Revise district laws to permit assessments of benefits, periodically equalized or on *ad valorem* basis.
- (b) To permit limited individual liability and privilege of paying out at any interest date.

The advantages of such a proposition would seem to be: (1) That it would give lower interest and easier terms of repayment to farmers who are now on the land and those who may come later. (2) It would provide for settlement with creditors in cash instead of refinance paper. (3) It would be good governmental policy, inasmuch as it would save existing values, increase the tax base, equalize the advantages to some extent with federal projects, and clean the slate for a future orderly

program of extending the reclaimed area. Such a program seems so reasonable as to deserve the support of the nation.

QUESTIONS

1. What different classes of drainage benefits are recognized?
2. Under what conditions are damages allowed?
3. How are special benefits to roadways estimated?
4. State the arguments for assessment on a flat rate in arid sections.
5. Upon what principles are assessments of benefits based?
6. Outline one method of classifying land and calculating drainage taxes.
7. What are the main items of cost in a drainage district?
8. What are the terms of the usual drainage bonds?
9. How is the rate of repayment graduated on a 6 per cent five to twenty year bond?
10. What factors would help determine the value of a drainage bond issue?
11. How is interest on drainage bonds guaranteed in Oregon?
12. What advantages are claimed for State Guarantee of bond interest during the first five years?
13. How do state and federal experiment stations aid in drainage development?
14. How does the States Relations Service assist in drainage?
15. Outline a plan for refinancing established, meritorious reclamation projects.

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CHAPTER XV

LARGE TILES vs. OPEN DITCHES

The best tile system ever laid would be a failure without an outlet. Every tile-line must have an outlet, whether it be into an open ditch or into another larger tile-line.

Nature's Outlet.— The natural outlet is the open ditch; but, unfortunately, Nature has left many of her outlets in bad shape. She leaves them in the form of winding rivers, often



FIG. 71. The Grande Ronde River, Oregon, showing oxbow meanderings;

150 feet wide and very shallow, with a fall of perhaps a foot to the mile, often even less. When the channel is deepened and straightened this may be sufficient. The unfortunate thing about the straight, narrow, deep ditch is that it is not natural, and Nature at once undertakes to undo the work of man, making the ditch winding and sinuous; and in a few months or years, at most, man has his work to do over again.

Large Tiles vs. the Open Ditch.— For the large winding stream the straight, open ditch is, of course, the only satisfactory substitute; but for the narrow, sluggish, winding stream whose surface is but little below the surface of the ground, the

covered tile-drain may be substituted. The smooth, straight walls of the tile-drain offer much less friction to the flow of water than the rough, irregular sides and bottoms of open ditches; therefore, a tile-opening much smaller than the ditch-opening will carry an equal amount of water. It is thus apparent that for smaller streams the covered drain of big tile is much to be preferred, especially where the original open drain or creek-bed is dry for a large part of the year. There are cases, however, between the extremes of the large river and the small open ditch where local conditions must determine which is the better outlet, an open ditch or a big, covered pipe. Sometimes a broad surface run for flood-water may be used in combination with pipes of moderate capacity. Open drains are unsightly. They harbor noxious weeds and underbrush and. They occupy valuable land and increase the difficulties of cultivation by



FIG. 72 Building main drain with half-yard dipper operated by a Fordson engine, Oregon State College farm.

cutting the land into irregular shapes. They necessitate the construction of bridges and culverts. They require more or less cleaning each year. Although with open ditches there are no pipes to buy, and the original cost may therefore be less, it must be remembered that consideration of first cost alone has caused many a man to lose a fortune.

The chief difference between the open ditch and the covered tile-drain is that when the tile-drain is properly finished and covered, expense, except for interest on money invested, is very moderate. The life of the tile-drain is generally unlimited. With the open ditch, on the other hand, first cost is only the beginning. Each year the interest on the investment must be met in



FIG. 73. Outlet ditch of Malheur Drainage District. (Photo by Barr & Cunningham.)

addition, there are maintenance charges for cleaning and clearing and repair of fences; and there is the annual loss due to failure to grow a crop on the ditch right of way.

The open ditch must always be dug deep enough to furnish an outlet for lateral drains. It must be at least 6 feet deep, while the bottom width must be sufficient to allow a team and scraper to work, or about 4 feet. The side slopes

should not be steeper than 1 foot horizontal to 1 foot vertical. Thus all ditches below a certain capacity must be made of one size in order to facilitate working with construction machinery. Cases may therefore occur in which the comparative cost of an open ditch is greater than for the covered drain.

To illustrate: A certain outlet drain is to carry 4 cubic feet of drainage-water per second. A question arises as to whether it is better to build an open ditch or a covered concrete drainpipe. The slope is 5 feet to the mile. The ditch must have the following dimensions:

Depth.....	6 feet
Width at bottom.....	4 feet
Side slopes	1 to 1
Yardage per rod.....	37 yards

LARGE TILES VS. OPEN DITCHES

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Cost of excavation at \$0.131/2 a yard ($\$0.131/2 \times 37$).....	\$5.00
Fence on both sides per rod.....	1.00
2 rods right of way at \$0.50 a sq. rd.....	1.00
1-8 ft. Bridge every quarter mile, tile inlets, etc.....	1.00
Leveling banks.....	1.00
\$0.20 Maintenance per rod capitalized at 5 per cent.....	4.00
Total cost per rod.....	\$13.00

Now, an 18-inch concrete tile will carry this water on this slope, and the cost will be as follows:

18-inch tile at \$0.60 a ft	\$9.90
Trenching, laying, backfilling.....	4.00
Total cost per rod.....	\$13.90

There being no right of way, fences, maintenance charges, or bridges, it is clear that in this case concrete tiling is the cheaper.

Professor E. R. Jones of the University of Wisconsin says, " I believe that an open ditch 6 feet deep, 4 feet wide at the bottom and 16 feet wide at the top, is the smallest open ditch that has a right to exist as an outlet drain."

Where there are 4 or 5 miles of such ditching, the excavating can be done for \$5 a rod. But to this be added at least \$8 more for right of way, maintenance, bridges, fences, leveling banks, etc., making a total of \$13 a rod. But \$13 a rod will lay an 18-inch covered drain, complete; and the trouble

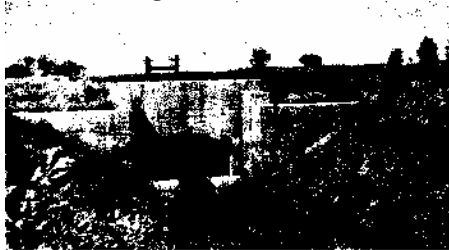


FIG. 74. A bypass for drain from Devil's Slough, under Hennepin Canal in Illinois.

about maintenance is forever out of the way; besides, there are no bridges, no fences, no steep banks, and the land may be cultivated over the drain.

Tiling 5 feet deep is better than a ditch 6 feet deep, because there are few ditches that will not silt up to the depth of a foot, even with the very best care.

Dredges cannot dig ditches narrower than 4 feet on the bottom and 16 feet on top. If a ditch of these dimensions is wide enough at the outlet, it is too wide at the upper end. With pipes, on the other hand, a drain which is 18 inches at the outlet can be gradually decreased to 6 inches at the upper or head end.

Advantages of Large Pipes— Large pipes well laid eliminate many difficulties.

- (1) There are no ditch-bottoms bulging upward from the weight of the soil-bank on the side.
- (2) There is no slush settling into the bottom to cause trouble for years to come.
- (3) There are no caving sides where 10 or 15 wagon loads of dirt fall at a time into the ditch-bottom to stop the drainage.
- (4) There are no damages to the property which is crossed by a covered tile-drain.
- (5) Covered outlet drains are usually accompanied by a liberal system of covered laterals, which drain the surrounding soil to such an extent that it acts as a reservoir for flood-water in the flood season, thus giving the pipes several days in which to carry off the flood-water; whereas when only open ditches are used, the flood-water rushes off in a few hours, requiring much larger outlet capacity.
- (6) In irrigated country, open drainage ditches give trouble from excessive growth of vegetation in the drain. If covered drains are used, the principal troubles encountered are from the roots of trees, quicksand, and "blowouts." Trouble from tree roots can be avoided by cutting away the trees in the immediate vicinity of the drain. Quicksand can be kept out by filling the trench with gravel both below and above the tile or by using corrugated metal pipe.

A recent report by Marsden gives the average annual main tenance cost of 106 drainage districts in the upper Mississippi Valley having tile outlet drains, as about two-thirds of one per cent, while for open ditches it was found to be about five per cent. The average annual cost may be nearly equal where the first cost of tiling is 70 to 100 per cent greater.

Practice in the humid sections tends more toward the use of the covered drain. Tiles having a diameter of 3 feet are not uncommon, and larger sizes are sometimes employed. Conservative estimates made by the United States Department of Agriculture show that it is generally more economical to use 20-inch tiles than an open ditch of the same capacity.

QUESTIONS

1. Why is the velocity less in a winding river than in an open drainage ditch?
2. How does the straightening and deepening of the river channel increase its capacity to carry water?
3. Why do farmers object to building an open ditch through their farms?
4. How does the covered drain meet this objection?
5. Name five points in favor of the covered drain, rather than the open ditch, for an outlet.
6. What items must be considered in calculating the total cost of an open ditch?
7. How many and which of these items drop out in case of the covered drain?
8. At what size of tiling does it become more economical to substitute the open ditch?

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CHAPTER XVI

DESIGN, CONSTRUCTION AND MAINTENANCE OF OPEN DITCHES

Nature has left most of her outlets in bad shape, so that a great amount of design and construction work is necessary in the utilization even of natural outlets. In case of the use of sluggish winding streams as outlets, cleaning, deepening and straightening the natural channel will usually give sufficient capacity to the stream to make it serve properly as an outlet. It sometimes occurs, however, that the old stream-bed is so littered with fallen trees, growing timber, underbrush and log-jams that it is really more economical to dig an entirely new channel some distance away, to avoid the expense of clearing. Again

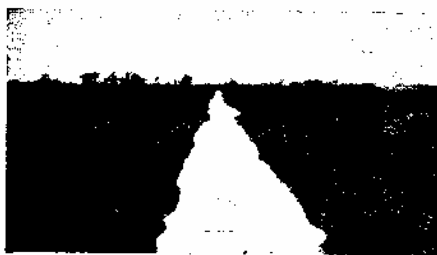


FIG. 75. Drainage outlet canal from Devil's Slough Drainage District, Illinois. This canal is in good condition

there may be no natural outlet channel at all, in which case an entirely new outlet channel is necessary.

Location of Open Ditches— The location of the open ditch should follow the general course of natural drainage as nearly as possible, with due regard to alignment. In the location of the outlet ditches, careful consideration should be given to the size and slope of the entire drainage area, so that the completed plan, when carried out, will be efficient and economical. No fixed rules can be laid down for location; but, in each case, a careful study of local conditions is essential. In the location

of open ditches, the following general points and the conflicting arguments arising from them should be kept in mind:

- (1) The value to stream flow of straight courses and gradual curves;
- (2) The desirability of locating drains along property lines wherever possible ;
- (3) The damage done to farms by ditches which cut off small inaccessible corners of fields, or extend across them in angling or irregular directions;
- (4) The economy of traversing natural depressions; and,
- (5) The injurious effect of unstable or caving soils on ditch construction and maintenance.

Before locating an open drain, an engineer should go over the entire route of natural drainage, investigating and comparing possible locations,



and lining out tentative channels with lath and poles, later measuring and locating the line more accurately. This inspection will often disclose the possibility of draining to different outlets or shortening the line by cutoffs, and will necessitate a number of trial locations.

FIG. 76. Beaver Drainage District ditch, Oregon, when in poor condition.

Treatment. — Outlet systems require treatment different from that given lateral canals or small ditches intended to accomplish farm drainage directly. The former must usually follow the natural depressions and water courses, while the latter must be located with strict regard to the source of the drainage-water, as is the case with tile-drains. Wherever practicable, small open lateral ditches should extend along the highways, as the roadway is thus drained and less right of way will be required. Further-

more, the waste banks can be thrown into the roadway and crowned, making an excellent thoroughfare where roads would ordinarily be impassable during the wet seasons.

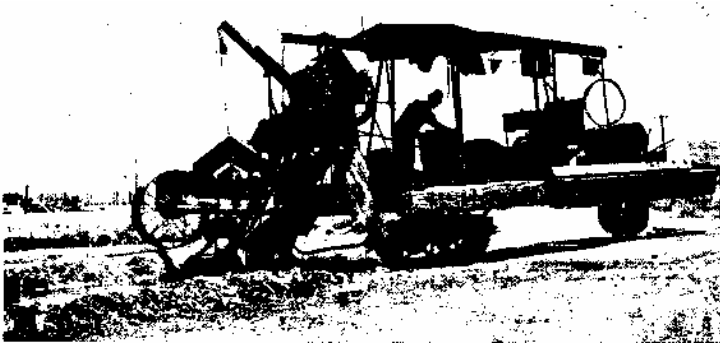


FIG. 77. Ruth ditcher cleaning ditch near Pocatello, Idaho.

Alignment and Curvature.— All ditches should be as straight as possible, and at the same time conform to the local topography. Short, sharp turns in the channel cause the moving water to come violently into contact with the bank, causing erosion, undermining and subsequent caving of the banks. Caving greatly reduces the capacity of the canal. The sharpness of the curves should depend on the size of the stream, the stability of the earth, and the velocity of the water; but the straighter the ditch, the cheaper maintenance will be

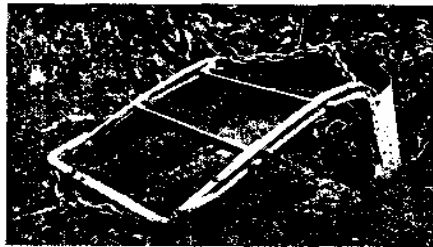


FIG. 78. Backfiller made of right and left - plows and road grader blade,

The proper curvature to give ditches when they are deflected from a straight line is a matter that requires careful attention. The adjustment of curvature to velocity of flow should be such that the

banks will not require artificial protection. The relation of bank erosion to curvature of the ditch and velocity of flow is intricate, owing to the variation in stability of different kinds of earth when subjected to action of flowing water. How short a curve may be used in large ditches, such as are constructed for drainage districts, without causing the banks to cave or wash, cannot be stated with mathematical exactness. However it is necessary to set certain limits for the curvature or "degree of curve" in good drainage practice. The "degree of curve" means the angle subtended at the center of the circle by a 100-foot chord. This is an engineer's arbitrary and convenient method of defining the radius of the curve. For example, a 1 degree curve has a radius of 5730 feet, a 2 degree curve has a radius of 5730 - 2 or 2865 feet, while a 10 degree curve has a radius of $5730 \div 10$ or 573 feet. Elliott gives the following general specifications for curvature:

For ditches with minimum bottom width of 6 feet and maximum grade of 2 feet to the mile, use a 20 degree curve (radius 288 feet).

For ditches with a bottom width of 6 feet and grade of 3 to 6 feet to the mile, use a 12 degree curve (radius 478 feet).

For larger ditches and greater fall, or for ditches with the dimensions given but with greater fall than that indicated, 6 to 12 degree curves are used, according to the particular conditions.

Grades.— Nature, to a large extent, fixes the fall or grade of a ditch. Natural channels are, in general, longer than artificial channels, owing to the unnecessary curves in the former. It therefore often happens that Nature does not provide enough fall for the natural channel. When artificially straightened, the channel may be so shortened as to cause an excessive grade. It is always necessary to make the artificial ditch conform in grade and cross-section to the fall provided by Nature.

But to decide what will constitute a satisfactory grade involves a consideration not only of the requirements of the ditch, but also of the nature of the earth. The grade should be as uniform as practicable. It may vary from 6 inches to the mile to 5 feet to the mile, where gravity ditches are used, or may be

less than 3 inches to the mile, when pumps are used. Ditches in some soils with grades above 3 feet to the mile are more difficult to keep in repair on account of the erosion caused by the rapid flow of water. In dense clay soils comparatively steep grades are permissible.

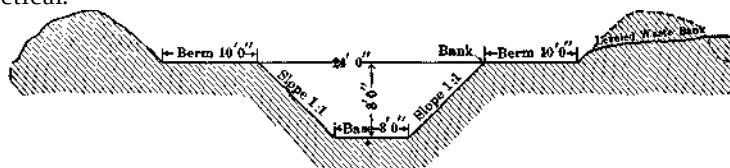
In flat country, all the fall available should be used in the design of the ditch, to make the ditch as nearly self-cleaning as possible. In heavy soils ditches with a fall of 4 feet to the mile may be considered self-cleaning, and larger ditches will clean themselves on flatter grades. When flat grades are used with small ditches, an increased maintenance cost must be expected, because there will be a tendency for the ditch to silt up. For this reason such flat grades as 6 inches to the mile, although often satisfactory, cannot be recommended.

Shape of Ditch Cross-Section— The resistance which any channel offers to the flow of water depends on three factors:

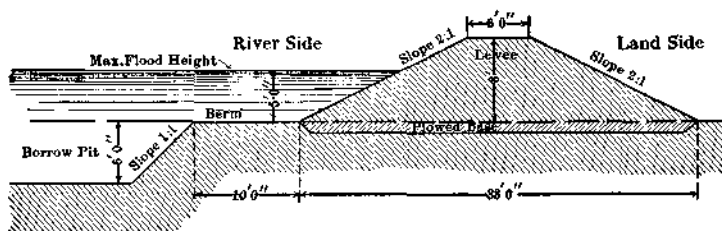
- (1) the slope of the ditch (which governs the velocity of the water);
- (2) the roughness of the surface with which the water comes into contact; and
- (3) the ratio of the area of the water cross-section to the length of "wetted perimeter," which is the bottom and side bounding line of the water cross-section. It is measured from the water-surface on one bank, down the bank to the bottom, across the bottom to the other bank, up the bank to the water-surface again, *but not across the water-surface*. Nature determines the first two factors, but the designer controls the third to a large extent. The greater the value of this ratio (area - wetted perimeter), the more water will flow in the ditch. Since the ratio, within practical limits of ditch construction, is greater for narrow, deep ditches than for wide, shallow ditches, the narrow, deep ditch is more desirable. This ratio is called the *hydraulic radius*.

Channels of semicircular shape offer less resistance to flow than any other form. Where the fall is slight, therefore, and it

is desirable to get the greatest ditch capacity with the least excavation, the ditch should be made deep and as nearly this shape as possible. But earth will not stand vertically without a retaining wall; therefore absolutely semicircular ditches are impractical. A half hexagon is more practical.



TYPICAL CROSS SECTION FOR OPEN DITCH



TYPICAL CROSS SECTION FOR 8 FT. LEVEE

FIG. 79. Cross-section of outlet ditch and levee.

Side Slopes— The rate of side slopes for open ditches depends on stability of the soil, though the method of excavation should be given some consideration. The angle at which the banks will stand depends on the fluidity of the soil when mixed with water; and, unless this angle is maintained, caving is certain to result. On the other hand, since the water has a tendency to widen the bottom and form a U-shaped ditch, it is not wise to make the side slopes too flat, as all excess soil in the lower corners will erode and silt up the ditch at other points. Again, if the slope is too steep, the upper banks will erode into the stream and partly fill the ditch.

Ordinary silty clay loam soil will stand with a slope of 1 foot horizontal to 1 vertical, or 45 degrees. Sandy or loose, loamy soils require flatter slopes of about 2 horizontal to 1 vertical, sometimes 3 horizontal to 1 vertical. Some kinds of peat will

stand nearly vertical. The action of the water always tends to widen the bottom of the ditch and make the sides more nearly vertical. Side slopes, as ordinarily constructed by dipper dredges, are 1/2 to 1, or nearly vertical, because a floating dredge cannot conveniently give the final slope to the bank. Contractors, frequently, dig the ditch to the required top width and then allow the banks to cave down to the natural slope. This is not desirable, because the final form the ditch will take can never be predicted; the ditch will cave and the unregulated caving will clog it. A machine which will give the banks their final slope is far more desirable than one which can leave nothing but a vertical bank.

Size of Cross-Section— It is necessary, before construction work can begin, to determine the size of the drainage channel. The two important factors in determining the size are the grade of the channel and the amount of surface runoff. Each of these factors must be carefully considered in determining the necessary capacity. From the necessary capacity and the available grade, the size of ditch can be computed. Good judgment must be exercised in adjusting the size of ditches to different parts of the drainage area, since it is necessary to consider physical conditions of soil and soil-surface in different localities, as well as the effect of unusual local storms.

In determining the size of open ditch necessary to provide drainage for a given area, one must know the rainfall, the runoff, and also whether underdrainage water is to be taken care of. For a maximum rainfall of 2 inches in twenty-four hours, the runoff would probably be 1/4 of this amount or about 1/2 inch. This amount holds for areas up to 2500 or 3000 acres. For larger areas the runoff is less, because the water is slower in reaching the ditch.

There are numerous formulas for the velocity of water in open ditches; but probably the simplest is the ChezyKutter Formula, which is repeated here:

$$V = C\sqrt{rs}$$
$$Q = AV$$

Explanation: V = velocity in feet per second

C = Kutter's coefficient

$r = A/p$

A = area in square feet of cross-section of water in the ditch

p = length of wetted perimeter, *i.e.*, the sum of the lengths down the sides as far as wet, and the bottom

s = the slope of the ditch expressed as the ratio of fall to length

Q = discharge in cubic feet per second

An open ditch must be sufficiently large to be reasonably safe against overflow or backing up of water into the laterals. To insure such safety 1/4 additional depth may be added to the calculated depth. It should be understood that the depth in the above-mentioned cases is the depth below desired water-level at flood stage, which may necessarily be several feet below the actual ground surface, in order to provide proper outlet facilities.

The following example will illustrate the method of computing the size of a small open ditch. In computing large ditches the depth is usually determined by depth of lateral drains, hence the bottom width becomes the variable.

A-certain small open ditch is to drain 2000 acres. Its bottom width must be 4 feet in order to allow teams to work conveniently, bank slopes of 1 to 1, fall 4 feet to the mile. What should be the depth below high-water level in the ditch, to carry the water if 0.75 inches is the maximum amount of water to be carried in twenty-four hours assuming " n " = .025.

Solution:

$$0.75 \text{ inches} = \frac{0.75}{12} \text{ feet}$$

Volume of water from one acre is

$$43560 \times \frac{0.75}{12} = 2722.5 \text{ (cubic feet)}$$

Volume of water from 2000 acres

$$2000 \times 2722.5 \text{ cu. ft.} = 5445000 \text{ cu. ft.}$$

in twenty-four hours. This requires a ditch with a capacity, Q , of 63 cubic feet per second.

From this point we must proceed by a "cut and try" method, "guessing" at a depth, then solving the problem with this assumed depth, noting the error and making a new guess until we find a depth which satisfies our formula for Q . Usually not more than two trials are necessary.

Thus:

Assume the depth to be 3 feet:

$$p = 4.242 + 4 + 4.242 = 12.484$$

top width is $(4 + 3 + 3)$

$$A = \frac{(4 + 3 + 3) + 4}{2} \times 3 = 21 \text{ sq. ft.}$$

$$r = \frac{21}{12.48} = 1.68$$

$$s = \frac{4}{5280} = .00758$$

from Table X with $n = .025$ and above values of r and s we find by interpolation:

$$C = 63 \text{ approximately}$$

Hence, since $V = C\sqrt{rs}$

$$V = 63\sqrt{1.68 \times .00758}$$

$$= 63 \times .036$$

$$= 2.27 \text{ feet per second}$$

and $Q = AV$

$$= 21 \times 2.27$$

$$= 47.67 \text{ cubic feet per second}$$

This is under the required capacity. The solution should now be repeated for, say, a depth of 3.6 ft. Then:

$$p = 5.09 + 4 + 5.09 = 14.18 \text{ ft.}$$

$$\text{top width is } (4 + 3.6 + 3.6) = 11.2 \text{ ft.}$$

$$A = \frac{(4 + 3.6 + 3.6) + 4}{2} \times 3.6 = 27.36 \text{ sq. ft.}$$

$$r = \frac{27.36}{14.18} = 1.93$$

$$s = \frac{4}{5280} = .00758$$

From Table X with $n = .025$ and above values of r and s we find by interpolation:

$$C = 64 \text{ approximately}$$

Hence, since $V = C\sqrt{rs}$

$$V = 64\sqrt{1.93 \times .000758}$$

$$= 64 \times .038$$

$$= 2.43 \text{ feet per second}$$

and

$$Q = 27.36 \times 2.43$$

$$= 66.48 \text{ cubic feet per second}$$

which is close enough to the required value. Usually two or three trials are sufficient to get the required result.

Ordinarily this calculation is not resorted to at all. The farmer builds a ditch and watches it for a few years; if it appears inadequate he deepens and widens it. But an engineer, after his surveys are made, must specify a certain size of ditch, in which event he either uses the above method or a set of tables calculated by the above formula, showing the proper size of ditch for various grades and drainage areas.

The following table gives the dimensions of a few typical ditches with side slopes of 1 to 1, which may serve as a guide in the selection of a proper size for the ditch. It is based upon R. B. Buckley's "Design of Channels for Irrigation or Drainage," to which reference may be made.

The column headed "condition of channel" illustrates the great effect of the coefficient of roughness, n , of the channel bed. The n is the value used in Kutter's formula for calculating C in the Chezy formula, $V = C\sqrt{rs}$. The channels marked "A" are suitable when discharge and depth are fixed

TABLE XXVI.—TYPICAL CHANNELS. SIDE SLOPES 1 TO
(BASED ON KUTTER'S FORMULA)

Base	Depth of water	Water-way	Velocity per sec.	Hydraulic radius	Condition of Channel			Kennedy's "critical velocity," per sec. V_c
					Very good	Good, average	Bad	
					$n = 0.020$	$n = 0.025$	$n = 0.030$	
Feet	Feet	Sq. ft.	Feet	Feet	Surface Slope. Unity in:—			Feet
Channels discharging about 5 cubic feet per second								
40.0	0.5	20.0	0.25	0.48	17,000	12,000	8,500	0.24
12.5 ¹	0.75 ¹	10.0	0.50	0.57	7,000 ¹	4,500	3,000	0.54
5.0	1.0	6.0	0.85	0.77	4,000	2,600	1,600	0.84
1.5	1.5	4.5	1.10	0.8	2,800	1,700	1,100	1.07
1.7	2.0	7.5	0.65	1.0	10,000	6,500	4,200	1.30
1.8	2.2	9.1	0.55	1.1	15,000	10,000	7,000	1.38
2.0	2.4	10.5	0.50	1.2	20,000	14,000	9,000	1.46
Channels discharging about 10 cubic feet per second								
26.0	0.75	20.0	0.50	0.71	10,000	7,000	4,400	0.54
10.5	1.0	11.5	0.85	0.86	5,000	3,200	2,000	0.84
4.5	1.5	9.0	1.10	1.03	4,000	2,600	1,700	1.07
2.0	2.0	8.0	1.30	1.05	3,000	1,900	1,300	1.30
2.2	2.6	12.5	0.80	1.3	10,000	6,500	4,500	1.54
2.3	2.8	14.3	0.70	1.4	15,000	9,000	6,000	1.62
2.6	3.0	16.8	0.60	1.5	20,000	14,000	9,500	1.70
Channels discharging about 25 cubic feet per second								
29.0	1.0	30.0	0.85	0.94	6,000	3,500	2,200	0.84
14.0	1.5	23.3	1.10	1.27	6,000	3,400	2,200	1.07
7.5	2.0	19.0	1.30	1.45	4,800	3,000	2,000	1.30
4.0	2.5	16.3	1.50	1.47	3,600	2,400	1,550	1.50
2.0	3.0	15.0	1.70	1.43	2,800	1,750	1,200	1.70
3.0	3.5	22.7	1.10	1.76	10,000	5,500	3,600	1.87
3.0	4.0	28.0	0.90	1.95	15,000	9,000	6,000	2.04
3.5	4.0	30.0	0.80	2.02	20,000	13,000	9,000	2.04
Channels discharging about 50 cubic feet per second								
58.0	1.0	59.0	0.85	0.97	6,000	3,600	2,400	0.84
17.0	2.0	38.0	1.30	1.67	6,000	3,600	2,600	1.30
11.0	2.5	33.7	1.50	1.86	5,500	3,400	2,200	1.50
7.0	3.0	30.0	1.70	1.93	4,400	2,800	1,800	1.70
4.0	3.5	26.3	1.90	1.89	3,400	2,200	1,400	1.87
2.5	4.0	26.0	2.00	1.88	3,000	1,900	1,300	2.04
4.0 ²	4.5 ²	38.3	1.30	2.29	10,000 ²	6,000	4,200	2.19
4.0	5.0	45.0	1.10	2.48	15,000	9,000	6,500	2.35
4.5	5.0	47.5	1.00	2.55	20,000	12,000	8,000	2.35

Example.—¹ A channel with 1 to 1 side slopes to carry 5 cubic feet per second on a slope of 1 in 7000 (n being = 0.020) which will be "non-silting" (on Kennedy's theory) should be 12.5 feet base with 0.75 foot of water.

² The "best discharging" channel, with 1 to 1 side slopes (by Neville's construction), to carry 50 cubic feet per second on a slope of 1 in 10,000 (n being = 0.020) should have 4 feet base and 4.5 feet of water; but the channel would silt as the velocity is too small. (195)

and ground will permit slopes indicated. The channels marked " B " are best if discharge only is fixed. Those marked " C " are best when discharge and slope are fixed and the depth may be variable.

The column headed "Kennedy's critical velocity, V_0 ," refers to the velocity at which no silting or scouring will occur. In other words it is the velocity which will maintain silt equilibrium at the depths indicated.

Bottom Widths.— The width of a ditch at its base is of particular importance, since, together with the grade and depth, it controls the capacity. Because of aggravating filling action in ditches serving drainage areas from 1000 to 4000 acres, the base width of main ditches should not be less than 8 feet. This is especially true where floating dredges are used, because they cannot operate in a narrower channel. Contractors securing ditches of narrower base width will excavate the top to a suitable width, in connection with a wider base, thus leaving side slopes too steep. It is therefore better, where dipper-dredges are used, to figure on an adequate base width in the first place and give the ditch the proper design for it.

In ditches for larger drainage areas, the bottom widths are determined by the capacity required.

Small ditches should never have a bottom width of less than 2 feet, else they cannot be easily cleaned with team and scraper. Where the fall is less than 3 feet to the mile, the base width should be at least 3 feet. It is impracticable to make narrower ditches or clean them except by hand labor. Where the fall is 10 feet or more to the mile, any form of ditch will be self-cleaning, and protective devices to prevent erosion will often be necessary.

Depths.— The depth must always be sufficient to provide ample outlet facilities for the lowest laterals, with 2 or 3 feet extra depth to provide for the silting up of the main canal which always takes place to that depth during the first few years after construction. The topography of the land through which a ditch passes largely determines the depth it must have.

Shallow ditches with wide bottoms are adaptable only for surface runs to carry off the surplus surface-water during flood

periods. In order to prove effective as an outlet for a tile-drain, and be reasonably permanent, an open ditch should never be constructed to a depth of less than 6 or 7 feet. This excludes the planning and construction of capstan or cable-plow ditches, because capstan ditches rarely exceed $2\frac{1}{2}$ feet in depth, and cannot be constructed to grade. Such ditches are expensive and inconvenient, to say the least.

In sand or peat soils, it is more difficult to determine the proper minimum depth. Sand overlaid with denser soils, such as are found in Malheur County, Oregon, is apt to run and cause caving of the overlying strata. In cases of such instability, it may be necessary to limit the depth so as to keep above the unstable stratum, or to construct a protective device such as a cunette to hold the sliding banks.

Waste Banks and Berms.— In ditch construction the earth excavated is piled in a ridge parallel to the bank, and at a certain distance from it. This pile of earth is called the waste bank. That part of the natural ground between the edge of the ditch and the spoil bank is called the "berm."

Waste banks are an inconvenience in the satisfactory cultivation of the adjacent fields. The excavated material, if thrown up by a dredge, is deposited in a wet and plastic condition, and on drying becomes very hard and tough. The waste banks for this reason are very hard to level down and cultivate before the banks have a chance to weather, but for convenience and appearance waste banks should always be partly leveled. Waste banks also act as a levee and prevent water from the adjacent field getting into the ditch. This objectionable feature may be overcome by leaving openings through or under the waste bank at the natural depressions along the ditch. Some engineers will make their waste banks continuous and provide structures for conveying the surface-drainage into the ditch. This prevents silt being carried into the ditch from the banks, and also keeps the banks up in better shape. Concrete, corrugated iron pipes and wooden structures may be used.

A clean berm is essential to all ditches. The purpose of the berm is to keep the weight of the waste bank from causing the

bank of the ditch to cave in. The following quotation will illustrate:

"The weight per linear foot of waste bank for a ditch of 20 feet base, 1 to 1 slopes, and 20 feet in depth, equals 1,481 pounds, wet earth being figured at 100 pounds per cubic foot. As the line of cleavage of the wedges of soil which tend to cave from the sides of any trench is always of curved shape, if the waste banks were deposited outside the surface extremity of this cleavage line, their sliding effect would be entirely prevented."¹

The proper width of berm depends therefore on the stability of the soil. Since the dipper-dredging machines cannot remove the waste farther than necessary to leave a clear berm of 6 to 8 feet, it is better to specify these widths and such side slopes as will insure against caving of the banks when the weight of the waste bank is considered. In case of very large, deep ditches, or in soft marsh, a clear berm of 8 to 12 feet should be specified, depending on the stability of the soil. Wide berms can be secured more easily by the use of machines, preferably of the dry land type with long booms.

The berms should be seeded and sodded to help hold the ditch bank from caving.

Safe Velocity of Flow in Ditches—Ditches must be made as nearly self-cleaning as possible, but this necessitates increasing the velocity of flow to the limit of safety when the water carries any quantity of silt. The safe velocity is the greatest velocity at which it is possible to let water flow in a ditch without causing erosion or washing of the banks. Kent's "Mechanical Engineers' Pocket Book " gives the following table of safe velocities in various soils:

	<i>Foot per Second</i>
Pure sand.....	1.1
Sandy soil 15 per cent clay.....	1.2
Sandy loam 40 per cent clay.....	1.8
Loamy soil 65 per cent clay.....	3.0
Clay loam 85 per cent clay.....	4.8
Agricultural clay 95 per cent clay.....	6.2
Clay	7.35

¹ Parsons, J. L., Land Drainage, p. 43, 1915.

Velocities depend not only on the fall but also on the depth and shape of the ditch, as well as on the roughness of the material of which it is constructed.

Character of Drainage Area— The character of the drainage area affects the rate of runoff and therefore influences the size of the ditch. A broad, flat drainage area will drain more slowly than an area of the same size but with steeper slope. In the latter case there is not only more water to be handled, because there is less time for percolation, but also a shorter time in which to move it than in the former case. This necessitates a much larger ditch in the case of a steeply sloping drainage area.

Broad, flat areas require larger ditches than long, narrow, flat areas, because in the former case the time of concentration of runoff is the same for all points, while in the latter case the concentration period for the lower end has passed long before the flood-water from the upper end comes down.

Amount of Runoff.—The amount of runoff is given as some fraction of an inch depth of water flowing off in twenty-four hours. This is called the "drainage coefficient." A drainage coefficient of $\frac{1}{2}$ inch in twenty-four hours indicates that the ditches must carry off $\frac{1}{2}$ inch of water from the surface of the whole drainage area in twenty-four hours.

A runoff of less than $\frac{1}{2}$ inch in twenty-four hours should never be considered in figuring the capacity of any open ditch. In the eastern states runoffs of 6 inches in twenty-four hours are not uncommon, and with small areas 1 inch an hour is a possible rate. In selecting a drainage coefficient, one must consider (1) the amount of rainfall and temperature, (2) topography, (3) size and shape of watershed, (4) slope of the land, (5) character of the soil, (6) vegetation and cultivation.

Rainfall and Temperature.— Localities having large annual rainfall have correspondingly large twenty-four-hour storm periods. Localities having warm climates generally need fully as much drainage capacity as cold climates, when the rainfalls are equal, for although the evaporation is greater, the violence of single storms is usually also greater in warm climates.

Topography. — Level areas require smaller coefficients than undulating, hilly areas, because they absorb more water, and the movement of the latter through the soil and over the surface is slower and more uniform.

The Size and Shape. — The ratio of drainage to rainfall is in general smaller for large areas than for small ones, due to the fact that the rainfall is seldom uniform over a large area, and also because the flood portion of the lower area may be drained off before the flood-water of the upper areas can get down to the lower part.

Character and Culture of the Land. — Undulating or rolling territory, with hard surface-like meadows, gives a higher runoff than cultivated lands. If hilly lands are terraced or under-drained the coefficient will be less.

Evaporation and Transpiration of Plants. — Careful experiments in France, Russia, and India show that at the end of the growing season, the water-table in wooded tracts is from 2 to 12 feet lower than in the open tracts adjoining. Forestry experts estimate that 40 per cent of the summer rainfall is caught or transpired by the leaves and again evaporated in wooded dis- tricts (6).

CONSTRUCTION

Hand and Team Work. — For ditches of small depth where the material is dry and the ground firm enough to support a team, team and scraper work can be done very economically, when the amount of earth to be removed does not exceed 30,000 cubic yards. The earth is first plowed and then removed with wheel or slip scrapers. The ditch may be finished by handwork.

Scrapers may be used on a cable so as to operate 20 or 30 feet back of the team. This permits cutting a rather deep ditch while the team is kept upon sodded surface ground. The slip scraper can be rolled into the trench when starting each cycle with the team.

A useful scraper for backfilling or excavating can be made by joining a right and a left plow with a road grader blade, Fig. 78.

In the irrigated section, or where the soil is water-logged, team work is in general not feasible because of the miry condition of the soil, and machine work must be resorted to.

Excavating Machines. — Ditches of greater size than 30,000 cubic yards are more economically dug by dredges. The latter are of two types.

1. Floating dredges.
2. Dry-land dredges.

The former have their machinery mounted on a barge with the engine in the rear, turntable and digging machinery in

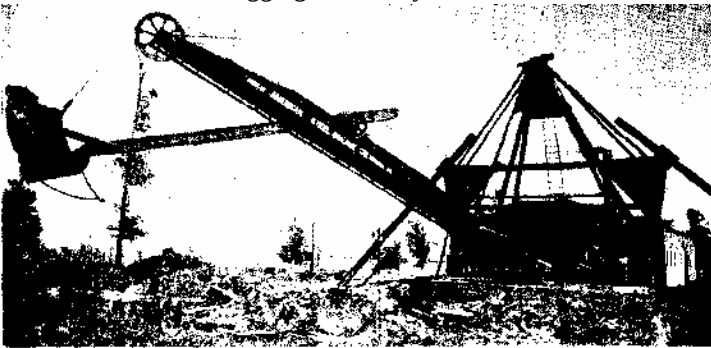


FIG. 80. A dipper dredge with bank spuds.

front. The excavator consists of a large dipper and boom or grab-bucket ranging in capacity from $\frac{1}{2}$ to 3 cubic yards, or more. The dipper type works much as the ordinary steam-shovel, except that the dipper is longer and has greater range. Floating dredges are adaptable to very wet land that is too soft to support heavy machinery.

Dry-land excavators usually begin work at the outlet and proceed upstream. Nearly all types have booms and turntables, the essential difference being in the type of bucket, which may be a drag-bucket, resembling a slip-scraper, a clam-shell, or an orange-peel bucket. There is also a templet or elevator and bucket type, as well as a wheel type, both of which give very smooth side slopes.

The floating dipper-dredge is the type of excavating machine most used though the more flexible drag line excavator is rapidly gaining in favor.

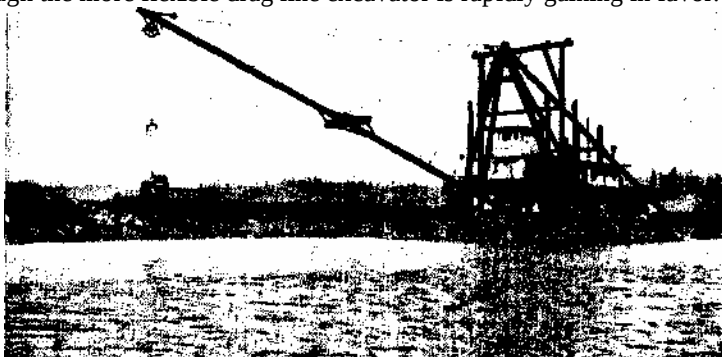


FIG. 81. Dredge with clam-shell bucket diking on the lower Columbia River.

Where many stumps are to be encountered, it is by far the most efficient type of machine. In wet land where the ditches have a cross-section of 100 to

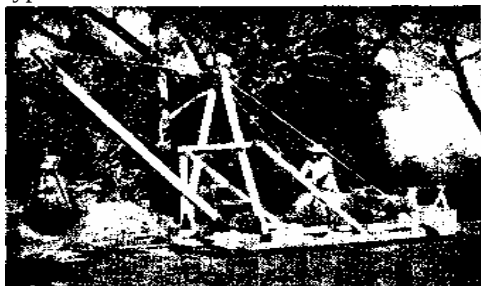


FIG. 82. A small dry-land excavator with orange-peel bucket.

1200 square feet, no other type of excavator will equal it for cheapness of operation. It is not adapted to levee construction because of its short reach. These dredges are made in capacities of $\frac{1}{2}$ cubic yard to 4 or 5 cubic yards, but the most common sizes are 1 to 2 cubic yards. They cost

from \$5000 up, the cost increasing rapidly with the size of bucket. To insure enough water to float it, this type is usually operated downstream. It

may, however, be worked upstream by building dams behind it.

The Orange-peel and Clam-shell Dredges are adapted to certain types of soil, where the material is soft and caves readily

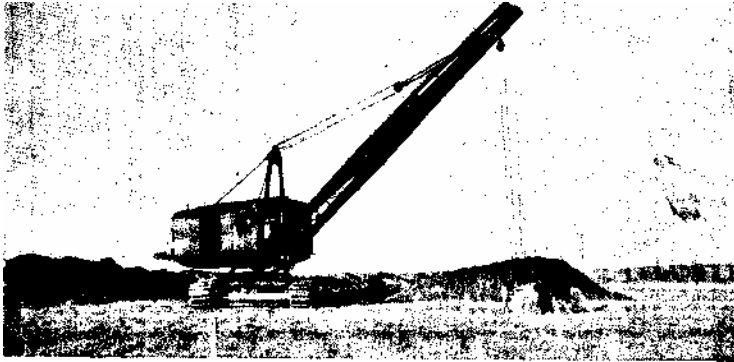


FIG. 83. Drag-line scraper excavator operated by electric power.

such as the muck of southern Louisiana. They are not adapted to soil where stumps are encountered. When provided with a long boom they are well adapted to levee construction.

The Drag-line Excavator has a bucket which operates like a slip-scraper. It is constantly increasing in favor for drainage work, and is especially adapted for large ditches and levee work, where the ground will support the machine. It is also suitable for ditch cleaning, and ditch banks can be more easily sloped with this type than with the other bucket or dipper types of dredge.

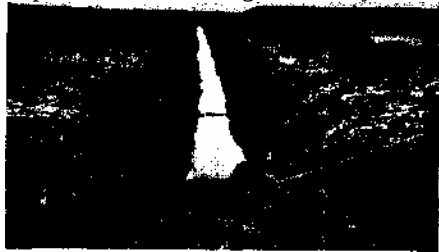


FIG. 84. Ditch excavated with the dragline excavator shown in Fig. 83.

The Templet Type of Excavator has a single bucket which moves along a guide frame shaped to the desired cross-section of ditch. The whole machine is mounted on caterpillar wheels or a track. It cuts a superior ditch under favorable conditions, but it cannot handle rock, stumps, or very hard earth.



FIG. 85. Hydraulic dredge at work on lower Columbia River.

The Wheel Type of Excavator has an excavating wheel which is attached to the rear of the machine and revolves on anti-friction wheels just outside the run of the main wheel. To the outer rim of the large wheel are fastened buckets, which, as the wheel revolves, cut slices of earth from the end of the ditch. With the addition of side knives, the wheel will cut a sloping ditch, the earth from the sides falling into the buckets. The ditches cut by this machine, because of their perfect bank slopes, are superior in hydraulic efficiency to those cut by most of the other excavators.

The Hydraulic or Centrifugal Dredge is not suited to open ditch construction, except in very fluid soils that will not stand in a spoil bank, or where the excavated material must be carried long distances and spread out evenly. Small types can be used successfully for cleaning old ditches. With the use of slope boards it has been found successful for levee construction.



FIG. 86. Discharge pipe of the dredge shown in Fig. 85.

Maintenance — A canal, to retain its efficiency, must be well maintained. Twice each year (more often if necessary) vegetation should be removed from the channel and banks, and such material as has fallen into the channel taken out. Any dam-

aged place must be repaired, to prevent further trouble. Tumbleweeds are a source of much annoyance, for they cannot be kept out of drainage canals. They soon form serious obstructions which must be removed at frequent intervals. This is generally done by men equipped with forks and rakes. Cultivation, however, seems to be effective in eliminating the nuisance. Another serious problem is "blow sand," which, during a high wind, may completely obstruct a canal in a few hours. The very nature of a drainage ditch makes maintenance difficult and costly; therefore, every endeavor should be made, during construction, to reduce the amount of maintenance necessary. Since the annual cost of maintaining open canals is often 10 per cent of the first cost, the need for correct design and careful construction is apparent.

Erosion. — Injury by

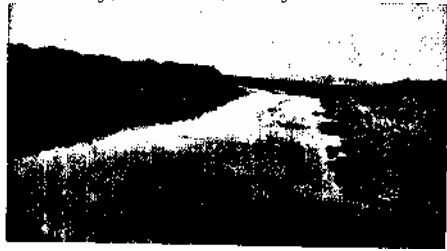


FIG. 87. A drainage canal excavated with floating dredge.

washing or erosion occurs either by direct wearing of banks and bottom through action of the water which carries the particles downstream, or by action of water on the soft substratum, thus undermining the bank structure and allowing the bank to cave. The erosive action varies as the square of the velocity; that is, if two streams have velocities of 2 and feet to the second respectively, their erosive power will be as to 9.

Erosion may be diminished by making the channel wider, thus increasing the wetted perimeter and decreasing the ratio of area of cross-section to wetted perimeter, which has the effect of increasing the resistance to flow and diminishing the velocity.

Keeping the channel smooth and clean will prevent erosion because it tends to keep the velocity uniform. In large canals, dams and dikes may be constructed to decrease the fall and divert the current from the ditch banks.

Character of Flow — We have already learned that for a given quantity of water and a specified velocity, the size of the cross-section is determined. Yet it is possible to vary the shape of this cross-section within certain limits. During the dry-weather flow the velocity should be sufficient to keep vegetation from growing in the ditch and silt from collecting on the bottom, thus eventually filling or stopping up the ditch. It is therefore necessary to make the bottom of the ditch narrow, so that the flow will be deeper, will cover the bottom, and will



FIG 88 Drainage canal with bank too steep and rough.

have sufficient velocity to keep down the aquatic plants. In a 10-foot ditch with a fall of 3 feet to the mile, an increase in depth from 2 to 8 feet increases the velocity of flow 45 per cent. Ditches with wide bottoms should not be used except where there is no dry-weather flow. In this case the bottom can be mowed with a mowing machine. The ditch banks should also be mowed twice a year; otherwise weeds and bushes will soon obstruct the ditch.

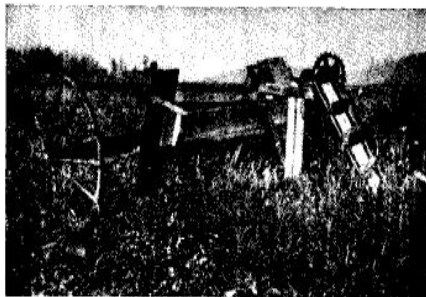
Curvature and Direction of Flow. — The alignment and curvature of ditches greatly influence the maintenance cost. At sharp curves the current tends to travel in a straight path; therefore it runs into the bank on the outside of the curve.

The section of the curve first struck receives the greatest force, and therefore erodes or washes away faster than the rest of the bank. For this reason the upstream end of a curve should be "eased off " or made of longer and longer radius until it becomes a straight line, so that the water will take the bend gradually and not wash into the outer bank.

Uniform Rate of Flow Throughout the Ditch is Essential. —

Practically all drainage water carries silt in suspension. Since its carrying capacity varies with the velocity of flow, if the velocity is decreased some of the silt will be dropped and a bar will form, obstructing the channel.

Ditch-cleaning. — Ditch-cleaning is an expensive form of maintenance. The wet, miry condition of stream-beds makes hand or team and scraper work almost impossible. On the other hand, the amount of material to be removed is so small as to make heavy machinery impracticable because of the great expense of moving the machines. Cleaning old ditches, there-a gasoline engine on a flatboat fore, may cost as high as \$0.50 a cubic yard, where the first cost may have been \$0.10 or less. The necessity of designing the ditches in the first place so as to make them self-cleaning cannot be over-emphasized.



Recently, hydraulic or centrifugal dredges of small size, with cutting wheels, have been designed and have proved their usefulness by cleaning old ditches quite economically.

The most recent development has had to do with the perfection of special endless chain and bucket ditch-cleaning machines with adjustable axle length, and with the economical and effective use of explosives for this purpose, Figs. 59-60.

Fencing Ditches. — **A Large Open Ditch Should Always be Fenced.**

— If stock are permitted to graze on the ditch banks, they will, by their continued tramping, cause the ditch banks to

cave gradually into the ditch and in time so completely fill it that its utility as a drainage ditch will be destroyed. This danger can be overcome in one way only; that is by keeping the stock off the ditch bank. All crossings should be bridged, because fording also has a tendency to fill the channel and cause silt to be washed down and deposited in some undesirable place. It is an erroneous impression, though a very popular one, that a ditch, once constructed, is there for all time. Only by careful oversight and protection can a ditch be kept efficient.

QUESTIONS

1. What is the purpose of an open ditch?
2. Tell in detail how to proceed with the calculation to determine whether to use an open ditch or a covered drain.
3. How many acre-feet per twenty-four hours are equivalent to one cubic foot per second? How many acre-inches?
4. On a slope of 5 feet to the mile an outlet drain is to be constructed to drain 500 acres at the rate of 1/4 inch of runoff each twenty-four hours. Assume that the open ditch must be 6 feet deep, 3 feet wide on the bottom, and side slopes 1 to 1; also that right of way cost \$0.50 a square rod; that the ditch can be dug for \$0.15 a cubic yard, fenced on both sides for \$1.00 per rod; that bridges 16 feet wide cost \$5.00 per linear foot; that ditch maintenance costs \$0.20 per year per rod; that 22-inch pipes will carry this water successfully on this slope. Find whether it is cheaper to use a tile-drain or an open ditch.
5. Calculate the same problem for a drainage area of 5000 acres assuming 54-inch tile is required costing \$3.60 per foot, exclusive of excavation.
6. What factors govern the location of open ditches?
7. Draw a sketch showing the proper design of the cross-section of an open ditch.
8. What is the objection to curves in ditches?
9. Of what importance is the grade of a ditch? How does it affect the capacity?
10. How does the shape of the ditch cross-section affect its capacity?
11. What is the objection to making the side slopes of a ditch vertical? What is the common slope adopted for stable earth?
12. What determines the bottom width of an open ditch? Of a tile-trench?
13. What is the minimum depth for a drainage ditch?
14. State the safe velocities of flow in soils of various kinds.
15. What is the effect on amount of drainage runoff of (a) Climate?

- (b) Rainfall? (c) Temperature? (d) Topography? (e) Size and slope of area?
 (f) Culture of the land? (g) Plant life?
16. For what size ditches are hand and team work economical?
 17. When should excavating machines be used?
 18. Name the various types of excavating machines and state to what type of work each is adapted.
 19. Where would you use a centrifugal suction dredge?
 20. Discuss the cost of machine work under various conditions.

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CHAPTER XVII

FLOOD CONTROL

The usual problems of flood control with which the engineer must deal are the protection of populous districts with storm water sewers and the protection of agricultural lands by means of proper drainage systems.

Closely allied with these works are channel improvements, levee construction, and flood storage works for the protection of city and agricultural areas from the flood waters of streams passing such areas. The greatest problem of the engineer is the protection of such areas from the periodic great floods, like the floods of 1913 in the Miami Valley of Ohio and the flood of 1927 in the lower Mississippi and Arkansas Valleys. Such protection must be effected by comprehensive works. These works may include the following five items:

- (1) Diversion and contraction works for deepening the low water channel across bars.
- (2) Canalization works or the construction of dams and locks for navigation purposes.
- (3) Dredging and removal of obstructions.
- (4) Impounding reservoirs for the storage of flood water for release in time of low water.
- (5) Levees which confine the flood waters utilizing them to deepen and enlarge the low water channel.

It is the fifth class of structures with which flood control from the agricultural standpoint is chiefly concerned.

Flood Damages. — In 1927 the Mississippi Valley was in the throes of the worst flood catastrophe that has ever overtaken it. Hundreds of lives were lost and millions of dollars' worth of damage was done. The levees below New Orleans were cut and whole parishes in lower Louisiana were abandoned to the flood

to save this great city. Numerous cities on the Arkansas and other tributaries were flooded and the call went out to the whole nation to assist in alleviating the suffering of the thousands who abandoned the flood plain and were temporarily homeless, and without shelter or food. There is no reason to suppose that other catastrophes like this will not occur. The floods of 1844 and 1883 on the Missouri and Ohio Rivers were very destructive. Floods, like the seasons, are periodic, and while man can hope to control them, he cannot stop them.

The urgent need of flood protection is illustrated in the following table which shows the enormous losses entailed in the great floods that occasionally occur along large alluvial streams.

TABLE XXVII

Locality	Date	Lives Lost	Property Damage in Dollars
Danube (Hungary)	1811		24 villages
Central Europe	1813	10,000	unknown
Neva Valley (Russia)	1824	10,000	unknown
Yellow River (China)	1851	(River changed course for 600 miles. Mouth moved 200 miles)	
France	1856		\$28,000,000
Pittsburg	1898-1908		1,200,000
Miami Valley	1913	400	100,500,000
Scioto Valley	1913		10,500,000
Seine Valley (Paris)	1310		200,000,000
Arkansas Valley	1921		19,000,000
San Antonio	1921		19,000,000
Mississippi Valley	1927	350	300,000,000

While the flood discharges are not perceptibly growing greater, the flood heights are increasing. This phenomenon is due to the obstruction of the flood plains with protective levees which construct the flood channel, and the deforestation of the drainage area which allows more rapid runoff of flood waters.

The flood plains of streams have been created by the streams themselves, through the centuries, with channels sufficient in size to accommodate only the normal annual floods that flow

through these channels. The occasional periodic high floods overflow these channel banks and cover the whole flood plain.

In the case of large rivers like the Mississippi and its tributaries, flood plains embrace large portions of many states. The flood plains are really a part of the reserve channel which nature has provided to accommodate the occasional large floods.

Methods of Flood Control. — In the colonization of every new country, the first settlements are made on the high ground adjacent to these flood plains, in localities most favorable for habitation, agriculture,

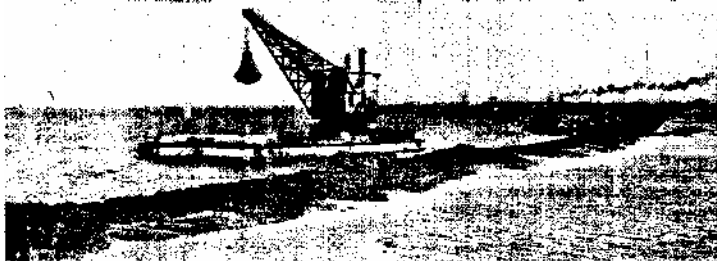


FIG. 90. Diking operations on Zuider Zee project. (Courtesy N. V. Vereenigde Bureaux, Amsterdam.)

commerce, anufacturing and other uses. Lands subject to overflow are at first ignored. As the population increases, however, and more cheap land is needed for agriculture, railways or manufacturing, men are driven to use the flood plains on which the rivers really have a prior claim. Bridges are built and protecting levees constructed without provision for extreme floods which occur at intervals of twenty, forty, or a hundred years. The regimen of a great alluvial stream is in such delicate balance that any artificial disturbance such as might be caused by the construction of a levee or an earth fill approach to a bridge may upset the whole scheme of nature in transporting the water through the territory. Whenever man encroaches on the right of way of nature, he must pay the price. If a wing dam or bridge approach is constructed across a flood plain, it forces an increase in velocity in the river bed at that point during the flood stage. This results in scouring

or eroding the bed and forming a bar or series of bars below where the stream velocity subsides.

For this reason, any attempt to control a large river must be made with extreme care and only with the advice and guidance of the best engineering talent available. Until levees can be located and built as a single unit and according to correct hydraulic engineering principles from beginning to end of the flood plain, they will always remain a temporary solution to the problem of flood control. These principles involve sufficient height to prevent overtopping in time of highest flood and sufficient contraction of the channel to maintain a uniform velocity so that deposit of silt and the formation of bars will be reduced to such a minimum as can be successfully and economically handled by dredging. A river flowing through a flat alluvial plain has a very low velocity of flow and continually deposits sediment in its own channel bottom. Building levees to confine the river to a definite channel may, therefore, be equivalent to courting future disasters unless sufficient velocity can be maintained to keep the bottom scoured out.

It is of first importance that runoff and rainfall studies be made to determine the maximum floods to be controlled.

1. French System of Diking. — The French system of river control would require a longitudinal dike along the bank or the outer side of the curves, of curved form and low elevation, to guide the low water flow.

In the United States the excessive cost of a longitudinal dike of rip-rap precludes its use for bank protection. The great scour in the river bed produced by such a dike requires large additional maintenance expense. Consequently, subaqueous brush mats weighted with stone to hold them in place have very generally been substituted. The upper bank is then paved with rip-rap, carefully laid stone, or concrete.

2. Use of Mattresses. — The mats are constructed from the extensive growth of willows which grow along the river banks in America and furnish a cheap material for use both in longitudinal and spur dike construction.

In the Mississippi River between St. Paul and St. Louis, the

brush is first made into " fascines " about 1 foot in diameter. These fascines are bound together by binding poles and laid parallel to the banks. Or the fascines may have a diameter of about 16 inches and may be laid perpendicular to the bank. Between Cairo and St. Louis, the brush is woven through the binding poles.

On the Missouri River, the willow brush used is smaller than on the Mississippi, and a method of weaving is used which gives the mattress the appearance of a woven basket. When



FIG. 91. Detail of mattress, Zuider Zee works.

lumber is cheap and brush is difficult to obtain, mattresses are sometimes woven of cull boards 4 to 8 inches in width. These cull boards are woven through binding poles similar to the fascine mattresses. This form of revetment has been successful on the Mississippi. These mattresses are woven continuously on board a platform which is constructed on the side of a river steamer. When the platform becomes filled with the mattress, the steamer's position is shifted by means of shore lines until a portion of the mattress is launched and the work of weaving is again continued.

The essential feature of a mattress is that it shall have sufficient thickness to protect the soil on which it is laid from the erosion of river currents, and sufficient flexibility to adapt itself to the

irregularities of the bank and bottom to be protected. The mattress must extend into the stream a sufficient distance to protect the slope and prevent the undermining effect due to the



FIG. 92. Finished dike, N. W. unit, Zuider Zee project.

increased scouring effect caused by revetment. Moreover, sufficient rock must be placed on the mattress to cause it to sink as fast as the channel is deepened at the mid-stream or channel



FIG. 93. Where Santiam River, Oregon, ruined 10 acres of fertile bottom land in one day.

edge as fast as the channel is deepened by scour. Willow brush mattresses become stiffer with age and unless plenty of rock is used to weight it down, an old mat cannot follow slight changes

in the channel bottom. The banks should always be given a gentle slope above low water before the mattresses are laid. If this is not done, a river falling after a high water will cause the banks to cave irregularly under the mattress, carrying portions of the mattress with it. Slopes as gentle as 4 :1 on the Mississippi are known to cause breaks in the mattresses at the low



FIG. 94. Coquille River control works.

water line, but such breaks are not serious, and can be repaired at low water.

Mattresses are also known to fail because of the passage of bank material through the mattress. This usually occurs at low water immediately following high water. It is caused by the seepage of ground-water from the banks through the mattress into the river. This danger can be forestalled by proper land drainage in the vicinity of the mattress-covered banks.

Mattress revetments on the outer curve (concave side) must also be protected by spur dikes on the inner curve or convex side of the channel. If this is not done, changes in direction of the current at high water may cause the current to hit the revetment at right angles at some point causing an eddy current of short radius which will erode a deep hole, undermine the mattress and allow a large portion of the revetment to slide into the river.

On large rivers, the upper bank above a revetment of brush and rip-rap should be graded to a slope of from 2 :1 to 4 :1, and paved with stones to a depth of one foot or concrete to depth of 4 inches to secure permanence of revetment. Concrete resists ice and wave action much better than loose stone.



FIG. 95. Destructive bank erosion under way. (Courtesy Woods Bros. Construction Co.)

3. Retards. — Permeable spur dikes as well as permeable longitudinal dikes have been used with good success on the silt-laden Missouri River. Longitudinal dikes induce a rapid fill, while floating debris and ice have little tendency to dislodge them. Longitudinal dikes, however, produce a scour against which the banks must be protected by revetment. On the upper Missouri River the retard has been substituted for the permeable dikes. Retards consist of a mass of trees whose butts are anchored to piles in the river bed. This forms an artificial structure like the drift which collects against a permeable dike. This structure checks the flow of water and induces a deposit of sediment, but is sufficiently flexible to let ice and heavy drift

pass over them without destroying the retard structure itself. Retards are efficient and successful substitutes for bank revetment when the river is not systematically regulated. They are particularly useful for detached protection of bridge landings, detached agricultural lands, etc. They adjust themselves to changes in the river more easily than mattresses, and they are



FIG. 96. Retard mattress and rubble work in place. (Courtesy Woods Bros. Construction Co.)

cheaper in localities where trees are easily available and stone is scarce.

Standard Current Retards — If the current velocity in a turbid stream is slowed down, the heavier sediment will be dropped and will form a bar in the river. The retard consists of a highly permeable dam made of trees, brush, and wire, interwoven together and held in place by steel cables anchored to "dead men" on shore and to concrete piles sunk in the stream bed above the retard. (Figs 97 and 98.) This brush and tree dam allows the river to flow through, much like a beaver dam in process of construction. Finally the brush becomes filled

with silt and sand and really becomes a solid bar through the natural action of the river.

Method of Construction of Retards. — The construction of a retard levee begins with the sinking of the anchor pile (preferably of concrete) (Fig. 97). The stock concrete pile of Woods Brothers Construction Company is 14 inches by 20 feet long, weighs 4000 pounds, and has a 4-inch well casing running

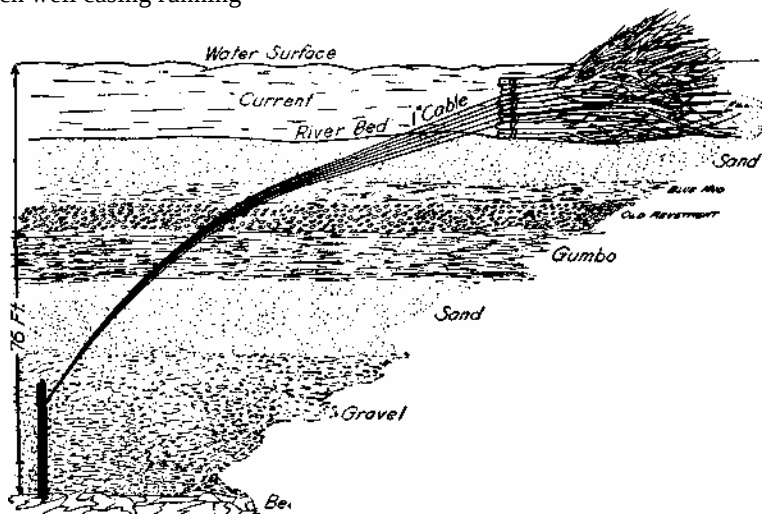


FIG. 97. Cross section of retard with submerged anchor piles. (Courtesy Woods Bros. Construction Co.)

through its core, and a 2-inch nozzle at the nose end of the pile. Side jets with street ells pointing upward lead out from this center hole at right angles to the pile axle about every 4 feet. These side jets help to lubricate and open up the hole when sinking the pile. The pile is handled by an "A" frame derrick on a steamboat or pile driver.

The first pile is driven about 15 feet from shore and about 100 feet upstream from the proposed location of the retard (Fig. 98). Other anchor piles may be driven at intervals up to 35 feet farther out toward the channel. When the pile is raised to position, a hose about 100 feet long is connected to the top of

the pile by means of a patented coupling. Six or 8 strands of 1-inch cable 200 feet in length are passed through an eye lined with a steel sleeve about 4 feet from the top end of the pile. The cables are then laid out straight and held in place by workmen. When the pile is in position for driving, the water is turned through the hose by means of a high pressure pump. The jet issuing from the nozzle in the nose of the pile bores a

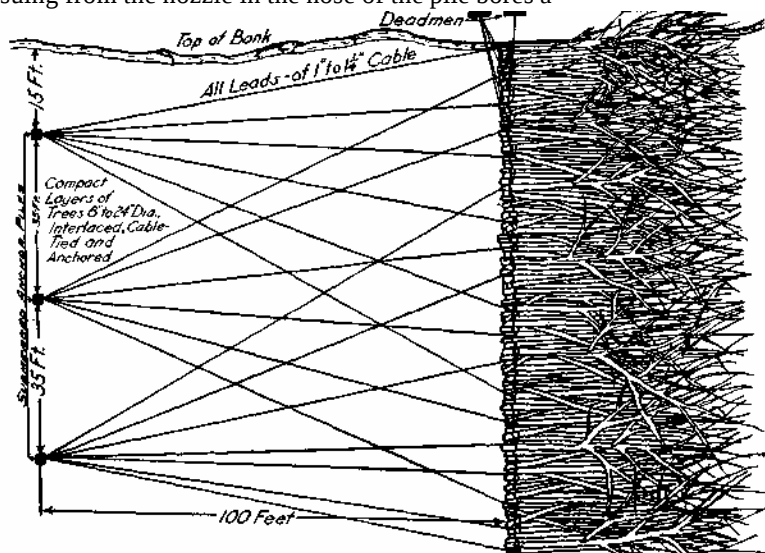


FIG. 98. Plan of river retard mattress. (Courtesy Woods Bros. Construction Co.)

hole in the sand bottom and the pile is allowed to sink down into this hole of its own weight. The spurting jets on the side of the pile keep the hole open until the pile is completely driven. It is customary to sink these piles 40 feet to 60 feet below the river bed. This puts them far below any possible future scour. One pile with its cable is used for each 35 linear feet of retard.

When the anchor piles are in place, a "dead man" is constructed on the shore where the retard is to be constructed. These "dead men" consist of large blocks of concrete sunk well

under ground on the bank and are used as a bank anchor. The retard mats are cabled fast to them to prevent the current from carrying them out into the main channel. Next, trees are cut for the retard structure. Only trees which are 8 inches or larger in diameter at the butt should be selected. These are dragged to the river banks with tractors or teams and "snaked" onto the work with a hoisting engine or moved into place by barge. (Fig 99.) A "half hitch" of cable around each tree

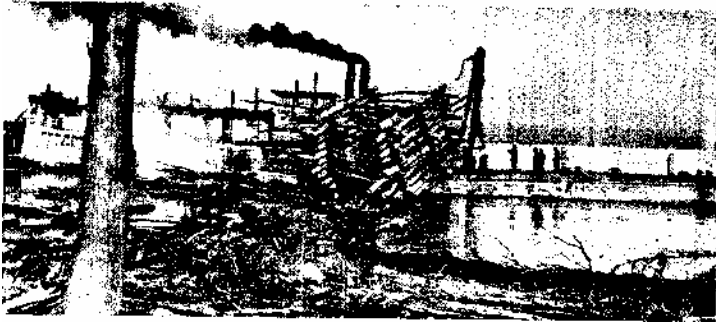


FIG. 99. Mattress material being placed from a barge. (Courtesy Woods Bros. Construction Co.)

is made and this is held in place with a 6inch staple. (Fig 100) A mat section of 18 to 35 trees is constructed and towed into place with a steamboat. Cable lines from the piles are interlaced with these mats to hold them in place. The cables from the shore "dead men" are also made fast to the mats in the same way (Fig. 101).

The method of anchorage, combined with swift water, causes the first layer of tree mats to sink to the bottom. More tree mats are added until the retard is built to the desired height and to the desired length across the stream. The completed retard is a solid mass of trees from bed of river to well above the water surface. The trees are firmly lashed together and form a substantial structure. The cables are interlaced so that the strain is well distributed and the retard is held firmly at the proper angle to the bank.

One retard is not, as a rule, sufficient. Retards must be arranged in a series or in batteries — see Fig. 102. The first one should be located well upstream above the point where the



FIG. 100. Trees cabled and anchored to retard stream. (Courtesy Woods Bros. Construction Co.)

bank is cutting. The number and spacing of retards of course varies with the local conditions and should be left to the judgment of a competent engineer. They are, however, usually



FIG. 101. Mattress structure cabled to stream bed and bank. (Courtesy Woods Bros. Construction Co.)

built from 500 feet to 1500 feet apart. Each retard extends from 100 to 400 feet into the river in the case of large rivers like the Missouri. The length of retard depends on three factors:

1. Radius of curvature of bank.
2. Velocity of the current.
3. Local conditions above and below the site.

The retard system of bank protection does not force immediate channel changes. They take place slowly and therefore more certainly. Bars sufficient to protect the bank will form in less than 90 days and will usually continue to build up for several years after the retard is built

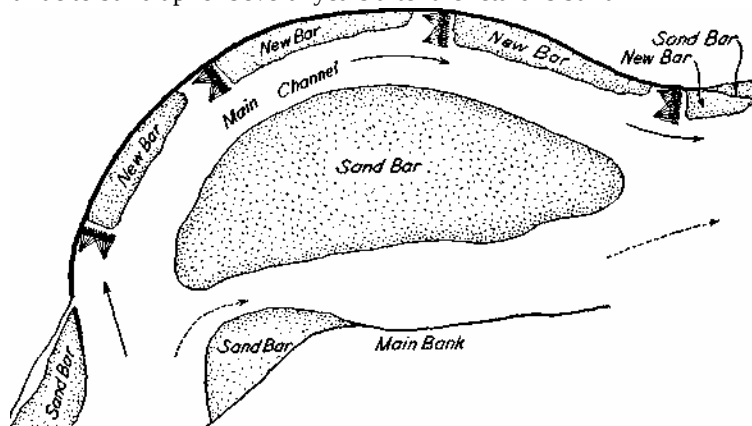


FIG. 102. Plan for retard mattresses along a curved river bank. (Courtesy Woods Bros. Construction Co.)

Bank Protection in Small Streams. — There are a great number of small streams and creeks which are relatively as destructive to banks as the larger rivers. Railroads, bridges, rights of way, farm lands, and like property, continually suffer by their invasions. Damage and destruction on the great navigable rivers has been so appalling that the genius and energy of the hydraulic engineering profession has been almost entirely directed to this phase of protection, to the neglect of the havoc worked by smaller streams and creeks. For use on small streams, however, there has been developed a steel retard that has been giving good results.¹

¹ Woods Brothers Construction Company, Lincoln, Nebraska. Steel Current Retard.

Steel Current Retards — The steel current retard is a patented device. It consists of a mass of trees at the bank end called the "bankhead," beyond which is anchored one or more lengths of the patented steel retard section as described below. The entire structure is fastened securely by steel cables to concrete "dead men" on shore and concrete piles sunk upstream to a point many feet below the river bed, as described for the large Standard Retards.

Steel Retard Unit — The retard unit is fabricated of steel angles and galvanized steel cables interlaced throughout the structure so as to strengthen the structure and form an entanglement which will catch the drift and debris that floats downstream. This drift forms a permeable dam which retards the current enough to cause a deposit of silt and the formation of a sand bar.

The steel units are built in 12-foot square sections. Each section may be bolted to an adjacent section, which makes it possible to build a retard of any desired length. The design may be modified to meet local conditions.

Bank-heads — As the steel units cannot be readily connected to the earth bank, a "bank-head" is used to fill the space between the first unit and the bank proper. This "bank head" consists of a mass of trees closely compacted and snugly fitted to the natural bank. These trees are cabled together, to the shore "dead men" and to the anchor piles upstream. This assures against their being washed out in high water. The anchor piles used are the same as those described above.

Another type of retard for small streams uses shore "dead men" entirely without the use of anchor piles.

Cost of Retards — The cost of current retards is very small in comparison to other devices that have been tried. The cost on the Missouri as reported at the National Drainage Congress at Kansas City in October, 1922, was \$5.75 per front foot of bank protected.

QUESTIONS

1. Name five classes of flood control structures.
2. Indicate the amount of loss in some of the principal historic floods.
3. Describe the different methods of diking.
4. What different types of mattresses are there?
5. Explain the effect of permeable retards.
6. How is reinforced piling placed for anchor piling?
7. What factors affect the length for retards?
8. What are "bank-heads" and how are they constructed?
9. What would be a reasonable cost per foot for river retards?

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CHAPTER XVIII

ESTIMATE OF COSTS OF DRAINAGE SYSTEMS

The Cost of Open Ditches — A ditch in Wisconsin, 6 feet wide at bottom, 7 feet deep, and 20 feet wide on top, costs \$1600 a mile when there are three or more miles to be dug. A single mile costs \$2500 or more.

Earth excavation is figured at so much for each cubic yard; the more dirt to be removed, the less will be the cost of each cubic yard. The cost may vary from \$0.05 to \$0.20, depending upon the size of the job, the machinery used, the ability of the contractor, and the character of the excavation.

When figuring on an acreage basis, a distinction must be made between farm drainage and outlet systems. The latter are intended only to afford outlet facilities to farm drainage systems; seldom are they designed to accomplish drainage directly without tile laterals. Plans for farm drainage systems presuppose that drainage outlets exist or that artificial outlets will be available. It is impossible to build an open ditch, however, that will not drain some land directly and this, of course, reduces the cost of farm drainage in the vicinity.

The cost of open ditch systems may vary from \$5.00 an acre to \$25.00 an acre. With the more expensive systems, as a rule, very little farm drainage is necessary; and, taking both farm drains and open ditches into consideration, the system may prove more economical than one costing much less but requiring more farm drainage.

Elements of Cost — The estimate of the cost of drainage work is a comparatively simple matter. It will usually contain comparatively few items, and they may be determined approximately from the local retail price lists of materials and the prevailing contract prices for similar work. Particularly important are those factors of cost which tend to increase or decrease

the cost after the estimate has been made, such as change in wages, unforeseen weather conditions, etc. These factors are items which the contractor or bidder must consider and they should always be recognized by the farmer. The price of labor, for example, may fluctuate 30 or 40 per cent during the completing of a single contract.

The factors to be considered in the cost estimates are therefore: (1) right of way. (2)cost of materials. (3)cost of delivery of materials. (4) cost of administration of contracts. (5)cost of depreciation of plant. (6) cost of financing contract. (7)cost of probable drainage claims. (8) cost of legal expenses. (9)cost of engineering.

Cost of Materials for Drains — The cost of tiling has already been discussed in the chapter on Costs and Profits of Tile Drainage. The engineer's estimates should itemize the cost of tiles, labor, materials, etc.

The principal materials needed for drain construction are: (1) tiles for covered drains. (2) gravel for concrete. (3) cement for concrete. (4) grates for outlets and inlets. (5) sewer-pipe for inlets and drains. (6) corrugated pipe for inlets, outlets, and culverts. (7) tile Y's for junctions. (8) sewer-pipe T's for junctions.

The following table from Parsons' "Land Drainage " gives the number of cubic yards per 100 foot station for different depths and widths of trench.

TABLE XXVIII. — WIDTHS AND YARDAGES OF LARGE TILE-TRENCHES PER STATION

Size of Tile Inches	Depth				
	3 feet	4 feet	5 feet	6 feet	7 feet
inches	inches cu. yds	inches cu. yds.	inches cu. yds.	inches cu. yds.	inches cu. yds.
5 and 6	12 11.1	14 17.2	18 27.8	18 33.3	20 43.0
7 and 8	14 12.9	16 19.7	19 29.3	19 35.1	21 45.4
10	16 14.8	17 21.0	20 30.7	20 36.9	22 47.4
12	18 16.7	18 22.2	21 32.4	21 38.9	23 49.8
14	20 18.4	20 24.6	22 33.9	22 40.7	24 51.8
15	22 20.3	22 27.1	24 37.0	24 44.4	25 53.9
16	24 22.2	24 29.6	26 40.0	26 48.0	26 56.0
18	26 24.0	26 32.0	28 43.1	28 51.8	28 60.4
20	28 25.9	28 34.5	30 46.3	30 55.5	30 64.8
22	30 27.8	30 37.0	32 49.3	32 59.1	32 69.0
24	32 29.6	32 39.4	34 52.4	34 62.9	34 73.4
	8 feet	9 feet	10 feet	11 feet	12 feet
inches cu. yds	inches cu. yds	inches cu. yds	inches cu. yds	inches cu. yds	inches cu. yds
5 and 6	20 49.2	22 61.0	22 67.8	24 81.5	26 96.0
7 and 8	21 51.9	23 64.0	24 74.1	26 88.0	28 103.6
10	22 54.2	24 66.7	25 77.0	27 91.7	29 107.6
12	23 56.9	25 69.3	26 80.0	28 95.0	30 111.1
14	24 59.9	26 72.0	28 86.3	30 101.9	32 118.2
15	26 64.0	28 77.7	30 92.6	32 108.4	34 125.8
16	28 69.0	30 83.3	32 98.5	34 115.3	36 133.3
18	30 74.1	32 88.7	34 104.8	36 122.2	38 140.4
20	32 78.8	34 94.3	36 111.1	38 128.7	40 148.0
22	34 83.8	36 100.0	38 117.0	40 135.7	42 155.6
24	36 88.9	38 105.3	40 123.3	42 142.6	44 162.7

The following tabulation shows approximate prices for ditches of different yardages:

<i>Yardages</i>	<i>No. Contracts</i>	<i>Cost per cubic yard</i>
50,000-100,000	13	\$0.131
125,000-200,000	11	0.105
225,000-300,000	5	0.092
325,000-500,000	6	0.091
over 500,000	4	0.085

Cost of Delivery of Materials — The cost of delivery is understood usually to include only the cost of hauling from the nearest railway station to the point where the drain is being constructed. The business way of paying for this item is to sublet the delivery to some one at so much a ton, withholding a certain percentage to insure completing delivery. Farmers are usually employed to do the hauling, however; and, as a rule, they will not agree to such a contract, but demand full payment as they go. Hard roads, level grades, and stable rights of way along the tile-line are conditions favorable to cheap delivery; but one steep hill or one boggy mud-hole on the route will very materially increase the cost of delivery per ton-mile. At \$5.00 a day for man and team, the cost of hauling averages \$0.50 to \$0.80 per ton-mile for the first mile, and \$0.20 to \$0.35 per ton-mile for each additional mile.

Plant Expenses — These include miscellaneous labor and materials expense and are usually underestimated. Sometimes shacks are needed for housing or boarding the laborers, in which case the cost is included in plant expense. Besides the cost of all tools, all trench, curbing and bracing, all blasting equip-ment, derricks, sand-boxes, dredging machinery, barges, and cabins for the same must be included, the latter forming a very large percentage.

Cost of Financing — This includes interest on borrowed credit. If the job is let by contract, the contractor must furnish a certified check on the amount of which he must either pay or lose the interest. If the district issues bonds to finance the project, the bonds may be sold at a discount or below par to make a

¹Cost Data compiled from Contracts by U. S. Bur. of Agri. Engineering.

ready sale. Personal bonds for the contractors and district officials must be given, interest on operating capital must be allowed for and must enter into the cost just as much as the price of labor and material.

Cost of Administration — The cost of administration of drainage construction usually amounts to a very nominal percentage of the total cost. On the smaller contracts local contractors fulfill the duties of manager, foreman, and office man in addition to the more expensive work of construction. On larger contracts involving more than \$15,000, a larger office force is necessary and the local contractor can no longer compete. In such a case administration may amount to from 3 to 6 per cent, depending on the character of the job and what is included under this head.

Other Contingent Expenses — Other contingent expenses are engineering and legal expenses, cost of printing notices, etc., and will amount to about 8 or 10 per cent on a project costing \$5000 and upwards. Engineering alone amounts to about 10 per cent for a project of \$2000 and to about 5 per cent for a project costing \$5000 or more.

Damage Claims. — These include the following items: (1) Contractor's damage losses, including the cost of damage suits for stock which may fall into ditches, accidents in blasting, etc. (2) Right-of-way damage losses, such as (a) actual cost of land occupied, (b) cost of fencing right of way, (c) cost of necessary bridges for farm operations, (d) damages to appearance of property and convenience of owner, (e) loss of value of small tracts cut off and isolated by open ditch.

Three-wire fencing with posts is figured complete at \$0.75 a rod, while woven wire is approximately \$1.20 to \$1.25. Bridges for farm purposes may be estimated at \$8.00 per linear foot.

More liberal damages would be allowed if farmers applied the damages to the intended purpose, instead of allowing their stock to cross the ditches and thus destroy them. Deterioration of farm values because of open ditch construction is not a legitimate claim, in spite of the natural aversion some people

may have. The inconvenience caused by the ditch is usually no worse than that caused by the natural condition of the land before the ditch was made.

Damages to railways for crossing their rights of way are usually prescribed by law without allowance for delay in traffic, building bridges, etc., which are regarded as inherent public liabilities of railway companies. Only the price of materials used in construction of drains across rights of way is allowed.

Cost of Machine Work — The cost of open ditch work is figured by the cubic yard. Usually, the greater the yardage to be removed, the less the cost for each cubic yard. On large jobs dredge or drag-line work is cheaper than team and scraper work, which latter costs \$0.20 to \$0.50 a cubic yard. On small jobs the opposite is true, because the cost of building or moving a dredge is quite high.

The cost for each yard of dredge work varies from \$0.06 or \$0.07 on large jobs to \$0.20 or \$0.30 on small jobs. This fact shows the wisdom of cooperation and the organization of as much territory as possible under one management.

The following costs for each cubic yard are compiled for different machines described in the U. S. Department of Agriculture, Bulletin 300.

TABLE XXIX. —COST OF MACHINE EXCAVATION

Size and Type of Machine	Length Miles	Top Width Feet	Bottom Width Feet	Depth Feet	Slopes	Width of Berm	Cost per Cubic Yard
$\frac{1}{2}$ yd. floating dipper-dredge.....	3 $\frac{1}{2}$	22-26	....	6-10	1-1	8	\$.0847
1 $\frac{1}{2}$ yd. floating dipper-dredge.....	....	30	....	5-6	....	....	.0221
1 $\frac{1}{2}$ yd. floating dipper-dredge.....	3	25	18	8	....	....	.41
1 yd. floating dipper-dredge.....	....	18	....	2	$\frac{1}{2}$ -1	....	.0512
2 yd. rotary drag-line.....	....	....	4-22	3-12	1-1	....	.1164
2 yd. rotary drag-line.....	....	....	4-22	3-12	1-1	8	.1273
1 $\frac{1}{2}$ yd. rotary drag-line.....	....	....	4-22	3-12	1-1	8	.1512
1 yd. dry land dipper.....	....	18	4	6 $\frac{1}{2}$	....	....	.1200
Templet excavator.....	1 $\frac{1}{2}$	....	24	3.5-7	1-1	15	.081
Wheel type.....	165	4	2	4	....	....	.0682
Wheel type.....	....	4 $\frac{1}{2}$	20 in.	4 $\frac{1}{2}$	....	....	.0793
1 $\frac{1}{2}$ yd. floating dipper-dredge.....	....	....	....	....	....	....	....
One year's work cleaning canal.....	....	....	....	....	....	....	.058
2 $\frac{1}{2}$ yd. rotary drag-line 225,000 cu. yds. in South Dakota.....	....	....	....	....	....	....	.0521
1 yd. dry land dipper-grab-bucket (Levee work).....	10	6	....	7	2-1	....	.074

QUESTIONS

1. How may excess fall be taken care of in an open drain?
2. How often should ditches be inspected and cleaned?
3. How should lateral ditches be brought into the main ditch?
4. What are the causes of erosion of ditches?
5. How may ditch erosion be controlled?
6. Why is a uniform rate of flow through the ditch essential?
7. Why is it important to fence outlet ditches?
8. What implements may be used in cleaning open ditches?
9. What factors enter into cost of an outlet system of open ditches?
10. How is cost of large tile-lines affected by depth?
11. How does the amount of yardage affect the cost per yard?
12. What damage claims may a contractor be asked to meet?

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PART III — SPECIAL DRAINAGE PROBLEMS

CHAPTER XIX

THE DRAINAGE OF TIDAL AND OVERFLOWED MARSH LANDS

Along the coasts there are large areas of land known as tide-lands ; and along the rivers leading to the coast we find bottom lands, to some extent affected by tides, and subject to overflow during the high water of early or late spring. In connection with these we may also consider certain areas of peat and muck which occur in the interior valleys. These lands are usually located where there is a remarkably long growing season, and are within reach of water-transportation and markets. They are composed of rich alluvial and vegetable accumulations, and, when reclaimed, are great forage producers. The one important factor limiting their maximum production is an excess of water. The reclamation of these lands is a comparatively quick, safe and permanent aid in increasing the food producing area.

On the John Jacob Astor Branch Experiment Station near Astoria, Oregon, the Oregon Agricultural College Experiment Station has some 50 acres of diked tide-land, for which a tile-drainage system was designed in 1915 and has since been partly installed.

Almost no underdrainage has been provided for the tide-lands, although this treatment will double the production of most of these wet pasture lands. Underdrainage, in short, will make it possible to kill out the rushes, grow legumes, and mature cultivated crops, so that crop rotation can be practiced.

Marsh Soils. — Marsh soils usually contain a large amount of organic matter, which gives them a peaty character. Such

soils, therefore, are usually light in weight, dark in color, and very spongy. They take up two or three times their weight of water and shrink upon drying. When dry, such soils usually possess a loose, dusty character.

Tide-Land. — Tide-lands occur as deltas or flat bottoms along the rivers and estuaries influenced by tide-water. The rise and fall of tides cause these streams to back up and overflow at high water, when their sediment is deposited along the bottoms. The coarser material is deposited first, or near the stream, giving rise to what is locally known as "bank land." Such land may be built up to the extreme high-water mark. Mud flats about the deltas are built up until they are exposed to the air during a part of the time, and water-loving vegetation gains a foothold. When this land attains an elevation above mean tide it may be considered for agricultural reclamation. The vegetation, before diking, consists of tussocks, rushes, sedges, sphagnum moss, and various other water-loving growths. These lands are usually cut by very irregular tide-sloughs, leading from the low parts of the tide-flat out through the "bank lands" into the open water.

The soil of typical tide-land is a silty muck, containing usually about 30 per cent organic matter, in addition to some inorganic material in the form of fine sandy silt. Fine sandy streaks may be encountered in the subsoil at depths of 4 or 5 feet, forming favorable layers in which to lay drains. Layers of vegetable matter from former sphagnum moss may be encountered in the subsoil, while the surface soil usually has a fibrous peaty structure.

Overflowed or Bottom-Land — At some distance from the coast, as a slight elevation is attained, the effect of the tide is of minor importance and the soil grades into silt loam. Dark silt loam is the prevailing type on the Columbia River bottom and other stream bottoms of that region; but there is fine sandy loam on some of the river bank land, and occasional layers of silt are encountered in the beds or margins of shallow ponds, lakes, or sloughs. Bodies of peat also occur. The undrained land of this type may contain 20 per cent of open water, though, under average conditions, the ponds are found to recede to small dimensions in dry weather. Perhaps

15 to 25 per cent may be covered with spruce, vine-maple, willow, steeple-brush, and other growths that require clearing and grubbing before the land can be cultivated.

In the unreclaimed state, this land is utilized for pasture for a short season. The same land, when reclaimed, should yield 4 tons of field peas and oats, or an equal tonnage of Alsike and timothy hay, as well as good crops of cereals, corn, potatoes, etc. The soil is deep and fertile, and, when utilized for forage crops in connection with dairying, it will pay interest on a valuation of \$150 to \$200 an acre. Under favorable conditions, especially near markets, there will be an increasing demand for this land for truck crops, which may pay interest on twice the valuation that dairying would justify.

Peat and Muck. — Peat and muck lands occur in areas aggregating 15 million acres in the northeastern United States, and in areas of similar extent in Florida, Canada, Sweden and Germany. There are some 6 million acres of peat in the United Kingdom. Three-fourths of the world's peat is reported to be in Soviet Russia, where there are some 57 million acres in European Russia alone, and a total of 325 million acres in the whole Union. The total peat area of the United States is about 100,000,000 acres.

The central portions of these bogs are usually filled with peat of medium to good depth; and shallow, peaty loam may occur around the margin. The outer part of the marsh area sometimes has considerable in-wash in the surface layers, so that a fairly well-balanced soil has developed. The coarse peat material becomes finer with cultivation. Cat-tail and bulrushes may occur on the deep peat in the native state, while the growth on the silty peat or muck is likely to be a mixed growth of willow, vine-maple, alder, and hardback. Sedge and willow growths indicate nearly neutral peat or "low-moor," while sphagnum usually predominate on highly acid "high-moor." The latter class is more often found in northern situations, and is of more limited agricultural value. This land in the raw state is of low productive value; but when reclaimed and brought into full

production it may be very valuable for onion growing and general truck or forage production.

Chemical Composition. — The total supply of organic matter and nitrogen is usually high in low-moor soils, although the nitrogen may be somewhat unavailable in new land. The phosphorous content is about average, though in some soils it seems to be a little below the average and rather unavailable, and super-phosphate is consequently used by commercial truck growers on the acid peat soil. There is a fair supply of potash in much of this soil, on account of the large amount of silt in-wash. These soils generally respond to potash fertilizers, which can be used with success on the deep peat under certain conditions in normal times. The chemical reaction of most of these soils is somewhat acid. With good drainage, however, the organic acids are removed or their accumulation prevented, so that very abundant crops may be secured without liming.

Tide-lands in the vicinity of Astoria have responded to liming where Alsike clover was grown, while in some instances the low-moor soils have not responded to the treatment. Numerous specific tests of the overflowed marshy land indicate that where thorough drainage is provided lime is not badly needed, at least during the first years after reclamation. These soils are generally deep, free-working, of high usable water capacity, and usually productive when drained.

Constructed and Feasible Projects. — The length of dike to the acre enclosed is less for compact areas or where only part of the boundary requires embankment. The feasibility of a project depends on location, demand for land, time and cost of reclamation, soil fertility, and probable agricultural value, as well as practicability of engineering features.

In some of the reclaimable marsh lands, larger protecting works, such as levees and outlet ditches, have been constructed. Numerous other feasible projects are contemplated or are under process of organization. The lands already diked are in need of further interior drainage and, in many cases, of some supplemental pumping to perfect their reclamation. A large part

of this land is capable of being brought into a good state of production in one or two years after drainage.

Dike Location. — Cooperation is important in order to get the largest enclosure with the shortest dike. Dikes should be located, where possible, on land of relatively good elevation; they should run at right angles or parallel to the stream, and should have a wide fore-shore, or strip of land on the outside to break the force of the stream. Natural brush protection can be turned to advantage if a hydraulic dredge is used. Soft slough bottoms and deep peat or coarse sand are not desirable materials for making



FIG. 103. A large concrete tide-box at Clatskanie, Oregon. There are five outlets, each five by six feet.

embankments; and a location can frequently be selected that will avoid running the embankment through such formations. Heavy silt or silty clay are desirable embanking materials.

Construction. — It is generally recommended that the top width of a levee should be twice the square root of the

height, and that it should be carried 3 feet or more above mean high tide. The side slope for good silt should be 3 of run to 1 of rise on the water-side. In sandy soil or in windy locations and below the water level 4 to 1 is better. Fine sandy loam or muck can be used successfully for embankment, if it is sluiced in with a hydraulic dredge or deposited in a saturated condition with a dipper-dredge. It is desirable, especially with peaty surface soil, to provide a muck ditch, by removing the original earth from the center of the dike-line to a depth of at least 2 or 3 feet, and then start to build the dike with excavated subsoil material, so that the dike is keyed in at the center. Logs, sod, and vegetation should be removed; and it is desirable to plow and remove the surface soil ahead of the embankment construction. The muck ditch can frequently be dug by means of

the dredge-dipper where all vegetation and logs have been removed, and scalping off the surface soil may be neglected. Where the hydraulic dredge is used it may be desirable to clear a muck ditch and leave the growth on the sides of the proposed levee as a protection against erosion. In crossing an old slough it is desirable to remove the muck in the slough and form the sides at the base of the new levee with piling. Shrinkage of the dike should be allowed for in any case, and will be greater in peat than in silt. Peat may shrink as much as 25 or 33 per cent. Where there are numerous tide sloughs, and seepage is anticipated, a borrow pit may be provided inside the dike to intercept seepage and lead small streams to a sluice-box, thus reducing the number of boxes.

The earliest dikes constructed in the vicinity of Astoria, Oregon, were built by hand labor, and a good spadesman was considered capable of building a rod a day. Most of these dikes have been strengthened by dredge work since that time. The floating dredge with a boom 80 to 100 feet long is desirable; it should puddle the levee in depositing saturated material. Where small stumps are to be handled, some contractors on the coast prefer the dipper-dredge. In normal times the common price for this work has been about \$0.10 a yard. Suction-dredges have been used on the Columbia River during recent years and have proved more economical than the floating dredge fitted with boom and dipper.

Maintenance — The embankment can be smoothed down with scrapers and, in two or three years, can be seeded over so as to afford good pasture. The presence of stock will tend to keep out rodents and pack the embankment, while the sod will protect from erosion. Where the embankment is subject to wave-action, rip-rapping with stone or lining with rows of piling to which a chain of logs is attached, will usually afford protection.

Tide-Boxes — The primary consideration in providing a tide-box is to allow ample capacity. Failure to do this has resulted in dissatisfaction and loss. Inquiry into the capacity of tide-boxes in the vicinity of Astoria and a study of the areas served by boxes considered of ample capacity, developed the fact that

an area of about 12 or 13 acres was being drained for each square foot of tide-box. These sluice-boxes should be strong, tight, and firmly placed. They should be located on a firm foundation and be provided with piling to which mud-sills are bolted at mean low tide. Numerous wing-walls should be provided and should extend well into the levee banks at frequent intervals along the box. The gate should be counter-weighted so as to move

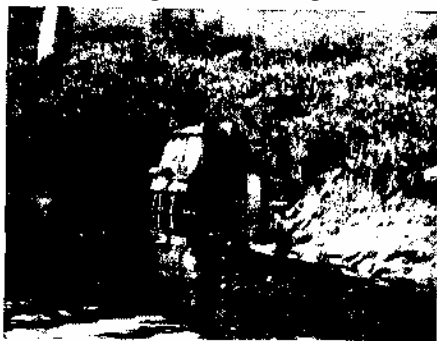


FIG. 104. Small wooden tide-box

easily, and should be set tight. Tongued and grooved piling can be used to coffer-dam the water while the pit is being excavated for a small tide-box, which can finally be set at the time of low tide. The larger boxes can be installed with the aid of a dredge at favorable tide. Creosoting will protect the lumber from deterioration. It is

recommended that the gate be made to fit tightly by the use of good rubber belting, and that the hardware used be galvanized iron or hard brass with link-hinges for the gate. The hinge for a small box may be made of a wooden pole and supported some distance above the box to

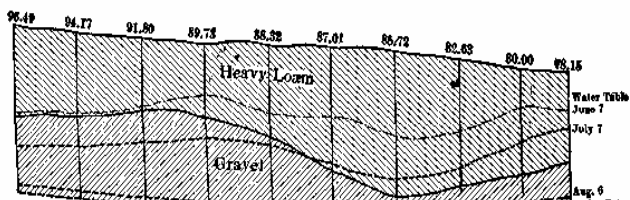


FIG. 105. Water table and substrata in Powder Valley, Oregon.

give added clearance. If any considerable number of gates are needed, it will probably be more economical and far more to purchase standardized products.

Settling Basins. — Where the fall is greater than is necessary, and the land within the area served by the sluice-boxes is low, it is frequently desirable to allow the turbid hill-water to spread out over the low area and deposit silt. Water can then be siphoned off, by -box carried above the surface of the ground so as to draw off only the clear water. This [process of filling low marshy areas known by French and Russian engineers as the commutation method. In England this is called “warping.”



FIG 106 Swamp land in Central Oregon before reclamation.

A small foot-hill ditch will frequently serve to pick up the hill-water along the margin of the marsh, and deposit it by gravity or through a separate sluice-box at the end of the dike. In such a ditch, settling-basins may need to be provided for deposition

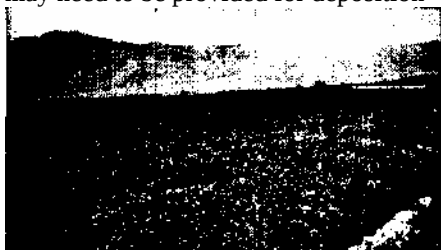


FIG. 107. Same locality as Fig. 106, after reclamation by drainage

of silt brought in from the hills.

Outlet Ditches. — Marshes on the coast and the lower Columbia frequently do not require any extensive amount of interior open ditches. An upland stream may enter and spread out on the marsh or traverse it in a meandering course.

A large stream may need to be straightened by dredging, or its sides may require banking to carry the water across the marsh to the open water on the outside. Some marshes in the Willamette Valley require an outlet ditch through the trough of the marsh and smaller foot-hill ditches

around the marsh borders. Outlet ditches should be made of ample depth to provide for the discharge from tile and should have broad side slopes. They should be reasonably straight,



FIG. 108. Drainage and irrigation ditches in tule peat land, Klamath Basin, Oregon.

and have as uniform a grade as practicable. The size of the ditch may depend somewhat on the grade. In most of the



FIG. 109. General view of drainage system peat land, Klamath Basin, Oregon.

marsh land the fall will be limited and the size will depend mainly upon the amount of water to be handled. This is affected by amount and distribution of rainfall, weather conditions,

topography, the size of the water-shed area, the nature of growth, and the kind of soil. The dredge used for the embankment will generally be used for interior ditches, unless perhaps a smaller one is required. A dredged ditch cannot be made narrower than 6 or 8 feet. Attention should be given to these interior ditches to guard against erosion, caving and injury by stock.

Pumping-Plants. — The mean tidal fluctuation on the Pacific Coast is but 5 to 7 feet, while on the North Atlantic Coast it is much greater. On the lower stream courses there are only a few hours, between the tides, during which sluice-boxes may operate. Again, much of the marsh land is within 3 feet of the mean water-level outside; and complete drainage, under such conditions, requires some pumping. Due to their low situations, wet bottom



FIG. 110. Tile drain filled with silt, due to poor outlet

lands away from tidal action require pumping for drainage. Water from the outlying drainage area, seepage through the dikes, and rain falling upon the surface may contribute to the excess water supply.

It is of first importance to study maximum storm and runoff conditions in order to carefully estimate maximum floods, and provide adequate capacity for protection.

The pump size refers to the inside diameter of the discharge pipe in inches. Centrifugal pumps should be operated at the economic speed, and this increases with the lift. Low speed pumps are efficient for low lifts. The velocity of water through the pump may approximate 10 feet per second, and this roughly indicates capacity. The pump capacity needed will vary with the size and slope of the district and contributing water-shed;

the storage capacity in ditches and basins; the amount and distribution of rainfall, runoff and seepage; the nature of soil; the kind of vegetation or crop; and the character of the interior drainage.

Pumps. — The centrifugal and screw types of pumps are most used for drainage, they are light and simple, and handle large quantities of water. Pumps for drainage should be set as low as possible while still keeping them above water. The plant should be carefully located on firm ground. A concrete base should be provided with threaded anchor bolts; the latter should have nuts below base plates, for leveling up before completing the concrete work. The suction and discharge-pipes should have few turns and these should be of large radius. Wing-walls and collars should be provided. The pipes should be no longer than necessary, and, in order to save power, should discharge at as low an elevation as possible. The supply-ditch will usually be a large tide-slough which provides some storage capacity, and this should have a trash rack at the approach to the intake pipe. The best modern pumps have double suction intakes and split casings. Provision should also be made for priming the pump. The capacity required may vary from $\frac{1}{4}$ to 1 or more acre-inch to the acre in twenty-four hours; $\frac{1}{3}$

inch has been found ample capacity for diked bottom-land in the vicinity of Portland. This is equivalent to about 9 second-feet per square mile. The capacity may be somewhat less for meadows than for crops that require complete drainage for maturity, such as potatoes and onions.

Power. — The power required will depend on the lift, volume and amount of friction. Each cubic foot lifted 8.8 feet per second represents one water horse-power and this sum should be doubled to allow for 50 per cent efficiency. Where electricity can be obtained at a moderate rate, a direct-connected motor in conjunction with a centrifugal pump makes a very satisfactory installation and requires very little attention. Where electricity cannot be obtained, Diesel or semi-Diesel engines may be employed. A small portable pumping outfit may be located on a barge and used for drainage or supplementary irrigation. A

small pump-house should be provided to protect the plant from the weather.

Cost of Pump Drainage — Cost of pumping includes (1) fixed charges, such as interest and depreciation on the first cost of the plant and (2) operating expenses, including labor, fuel, and lubricating oil, which collectively make up the total annual cost. This cost, distributed over the area, would give the total annual cost to the acre for pumping. Pumping-plants will be used more and more in connection with drainage and supplementary irrigation on the peat and overflowed lands, and, as a supplement to the sluice-boxes, to provide complete drainage near the coast.

A study of cost of pumping for drainage in the Upper Mississippi Valley, with a dozen typical illustrations, was made by John G. Sutton, Assistant Drainage Engineer, U. S. Bureau of Agricultural Engineering, and shows:

- (1) The unit cost of pumping varies with the cost of interest and depreciation on the plant, the cost of energy, labor, plant efficiency, lift, and quantity pumped, — called "plant factor."
- (2) Suitable capacity, reliability, first cost, durability, and cost of operation should be considered in selecting suitable plant equipment. The type of power should be chosen according to total cost per brake horse-power-hour, dependability and care required.
- (3) River seepage, and drainage from bluff lands, often increases cost of pumping.
- (4) The amount of power required per unit of lift per acre - foot is a basis for the comparison of two plants, especially below a 10-foot lift.
- (5) The cost of pumping per acre-foot is especially valuable for comparing plants operating under similar heads and plant factors.
- (6) The cost per brake horse-power-hour is the best unit of comparison for pumping with different types of power, difference in plant factors not being overlooked.

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- (7) Occasional tests by competent engineers will insure adjustments that make for efficiency.
- (8) Adjustments should be made to secure economic speed for the lift at hand, labor and time elements considered.
- (9) Frequent cleaning of pumps, piping and screens make for higher efficiency.
- (10) The pumping plant should be operated to render maximum economical service to the drainage district. Effective drainage may be realized at expense of plant efficiency during critical cropping periods.

Some Large Installations — District 108, California. — One of the larger pumping plants in the West is in use by Reclamation District No. 108 near Woodland, California, to control water on Sacramento River bottom lands. This plant consists of five 48-inch Wood-Screw-Pumps, driven by five 175 horse-power direct connected motors. The 48-inch pumps discharge approximately 100 second-feet each. (Fig.119.) The electric motors are in a water-tight basement. The cost of replacing the complete plant at the present time would be perhaps \$500,000. These pumps are said to be very efficient when operating against a low head and are coming to be much used for drainage.

In Reclamation District No. 108 water is pumped from the river for the irrigation of over 100,000 acres, the bulk of which is rice land and large pumping plants are provided to pump out drainage and flood waters from the lower part of the project. It is necessary to keep the surface of the rice land covered for several weeks but provision must be made to draw off the water before harvest as well as to protect against flood-water. Water grass, cat-tails and tules become troublesome after two or three years of rice growing and a cultivated crop such as Egyptian corn is then used to clean up the land. The general plan of drainage is to provide open ditches every half to three fourths of a mile to draw off the water below the irrigation system. In some instances the irrigation water must be flumed across these open drains. The soil is heavy clay and this together with the large volumes to be handled make underdrainage impracticable.

The length of period necessary to pump, kind of soil and

value of crops affect the feasibility of pumping for drainage. The total annual cost must be held down to a few dollars an acre to make pumping practicable for ordinary field crops.

Zuider Zee Pumping Plant, "Lely." —The Lely pumping plant serving three quarters of the 50,000 acres in the Northwest unit of the Zuider Zee project is named for the engineer who planned the works. This pumping station situated near Medemblik (Fig. 111) consists of three motor-driven, vertical shaft, centrifugal pumps, each having 86,000 g. p. m. normal

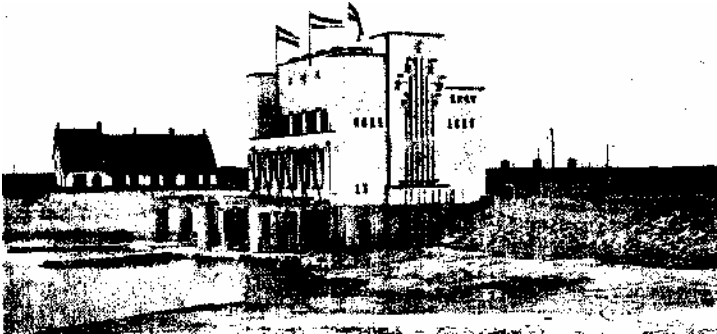


FIG. 111. Exterior of Lely main pumping plant, which serves the first 50,000 acre unit of Zuider Zee project, Holland.

capacity at 107 r. p. m. and a head of 20 feet. It is planned to remove $\frac{1}{3}$ inch depth of water per day from the drainage area, and to operate 1430 hours per year.

The pump house was erected on an enclosed area which was excavated and drained to 32 feet below normal sea level. Wood piling carries a reinforced concrete base on which concrete pump casings and races were constructed. The building is reinforced concrete. Its maximum height is 102 feet above the lower side of the foundation floor.

The pump impellers are 8 feet, 2 inches in diameter, and operate in grouted, asphalt painted concrete casings having metal shoulders.

Motors are 3000 volt, 3-phase synchronous, and of 900 H.P. at 107 r. p. m. and 50 cycles. The speed is varied from 88 to

120 r. p. m. by patent (Scherhiar) regulators. An interior view of the plant is shown. (Fig. 112.)

Interior Drainage. — Very little interior drainage has been provided in diked lands and almost no underdrainage has been employed. On the tide-lands an occasional box underdrain has been installed. The tile-drainage system on the Branch Experiment Station near Astoria, Oregon, is, so far as can be determined, the first thorough tile

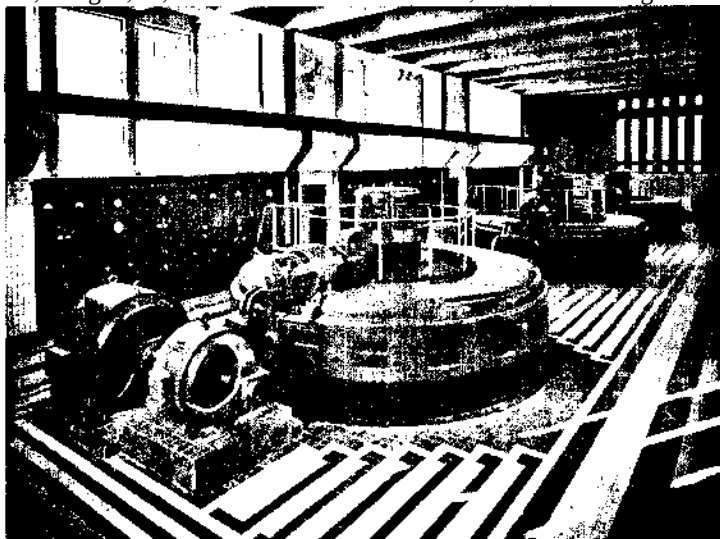


FIG. 112. Interior of the Lely pumping plant. (Courtesy Werkspoor, Amsterdam.)

system to be installed on tide-land on the west coast. In order to illustrate the problems to be encountered in draining such land and to explain the preliminary results of the experimental part of the system, its installation will be described.

In laying out this drainage system the existing sloughs were all sketched, and were taken into consideration in laying out the system for the main body of the farm in a random or natural system of drainage applicable to ordinary farm conditions.

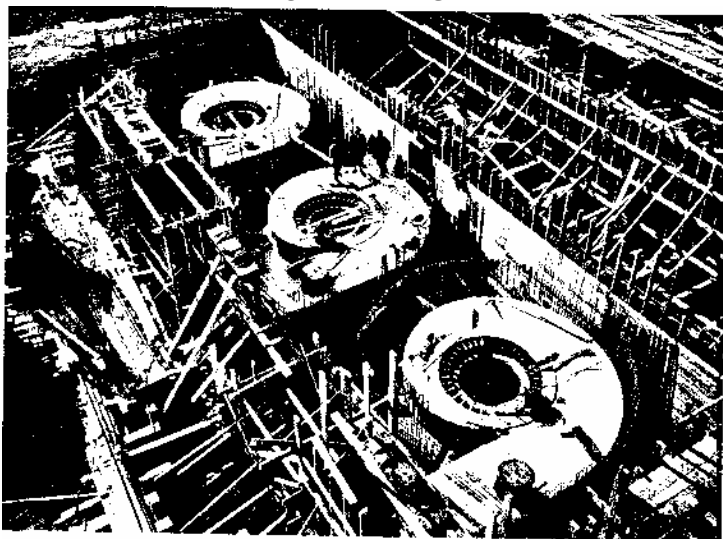


FIG. 113. View of the Lely plant in process of construction, showing great concrete casings for pump runners. (Courtesy Werkspoor.)



FIG. 114. View of old pumping plant, Medemblik, Holland, which discharges into Zuider Zee in foreground.

A soil-auger was used to study the subsoil and ground-water conditions, so as to locate drains where they would serve most efficiently.



FIG. 115. Scappoose, Oregon. Drainage District pump house and trash rack.

Excess water on this tide-land comes from (1) runoff from the hills and related springs near the base of the uplands, (2) seepage



FIG. 116. Headgate and canal on Ryon River delta, near Poti, U. S. S. R., for reclamation of low marshy land by silting or commutation. (Courtesy Dir. Exp. Sta. Poti.)

through the dikes, (3) excess ground-water due to precipitation on the low land itself. It was decided to run a main drain in the direction of the dike, and near the inner side of it, to intercept

seepage that appeared to be taking place there. This also led to small tide-sloughs which had been dosed off in constructing the dike, and contained standing water all summer, due to lack of outlet. Laterals were arranged to take up these sloughs, and a foot-hill ditch and underdrain were arranged to intercept

the water from the upland. Additional laterals were placed at fairly regular intervals to serve the remainder of the low interior fields.

Design of Underdrains. — In arranging interior tile systems for tide-land, where the field is broad, and low in the center, it is best to run the main through the center of the marsh and bring laterals to it from both sides. Where the field is low near the hill, and subject to seepage from the levee, mains of good capacity can be put along the edges of the marsh near the dike and at the base of the hill, and the laterals led to these mains. In the Astoria Branch Experiment Station drainage system, a section was arranged to determine by experiment the best depth and frequency for laterals.

In designing field drains for overflowed land, it may be necessary to carry an open ditch or tile along the inner side of the levee to collect seepage, and connect the small depressions and sloughs leading the excess water to the pumping station or



FIG. 117. Deep woody sphagnum peat profile showing lighter "grenz" layer, formed during dry climatic cycle, near Leningrad, U. S. S. R.

sluice-box. Where there is little seepage, the interior drainage on the overflow land will usually be only a random, or natural, system of drains to take care of the swales and depressions.

The ordinary peat bogs will require an outlet ditch through the trough or center of the bog and a foot-hill ditch or tile-line around each side. From these, parallel laterals may be run in such directions as will thoroughly drain the interior or remainder of the bog, with the least expenditure for junctions, double-drainage, or outlets. While the outlet ditch and foot-hill ditch may give sufficient drainage for pasture and meadows, if augmented by an open ditch at intervals of 300 or 500 feet, this will not permit complete drainage. To grow such crops as onions and potatoes properly, and draw off the water quickly in the spring, so that early planting can be accomplished, additional laterals 3 to 5 rods apart, arranged in parallel series, will be needed.

Experiments Relating to Depth and Frequency. — From the results of experiments at the Branch Experiment Station near Astoria, it appears that fairly good drainage will be provided where the tile-lines are placed 4 feet deep and 5 rods apart. Where this depth of outlet cannot be obtained, it may be necessary to put the tile-lines 3 feet deep and 4 rods apart to accomplish the same purpose.

In the overflowed land, parallel laterals are not likely to be needed. Here, a random system of drains, running through the main swales and ponds at a depth of 3 to $3\frac{1}{2}$ feet, will prove to be sufficient.

In the peat, or beaver-dam land, fair drainage for grasses may be provided by open ditches from 300 to 500 feet apart and 5 feet deep. To provide for early planting, however, and to bring this land into full production, or to obtain complete drainage for the ripening of crops such as onions and potatoes, it has been found desirable in practice to have laterals 4 feet deep and 3 to 4 rods apart, and in addition, to take care of any seepage or spring-water not collected by such parallel laterals. Four feet is a good minimum depth, as peat soil may shrink $\frac{1}{3}$ of its volume, due to more

rapid disintegration following drainage. If the water-table recedes below the tile-base, such shrinkage is

more apt to interfere with the grade of the tile-line. Flash-boards may be used to raise the water in drains and cause sub-irrigation at intervals.

Studies Relating to Size and Grade. — Pumping-plants on the overflowed land having capacity to handle 1/3 inch of water in twenty-four hours are considered adequate where operated regularly and for sufficient intervals of time. From preliminary data at hand, it appears that the main tile-drains



FIG. 118. Pumping plant on the fen or peat land near Ely, England, consisting of a 33-inch pump and five 50 H.-P. Diesel engines, and serving 13,000 acres.

on tide-lands on the north coast of Oregon should have capacity to handle an inch to the acre in twenty-four hours. On the south coast, on account of lighter rainfall, $\frac{3}{4}$ inch to the acre in twenty-four hours should be a reasonable capacity.

In the experimental tile system at the Branch Station near Astoria, the main drain is practically 6 feet deep at the outlet, while the upper end of the most distant lateral is less than 3 feet deep. The elevation of the land near the outlet is about 1 foot higher than in the most remote parts of the drainage system, which are 1200 feet distant. The fall used for the main drain is 0.16 of a foot for each hundred feet, and the laterals have a fall of 0.2 of a foot for each hundred feet.

Construction of Underdrains. — Underdrainage on marsh land can best be installed in the dry season, except where special conditions make other seasons suitable for the work.

The drainage system on the Branch Experiment Station at Astoria is practically the first thorough tile system on the west coast on such land, and as numerous difficulties are encountered in tiling tide-lands, this system will be described in some detail. The drainage system was designed by the writer, and installation

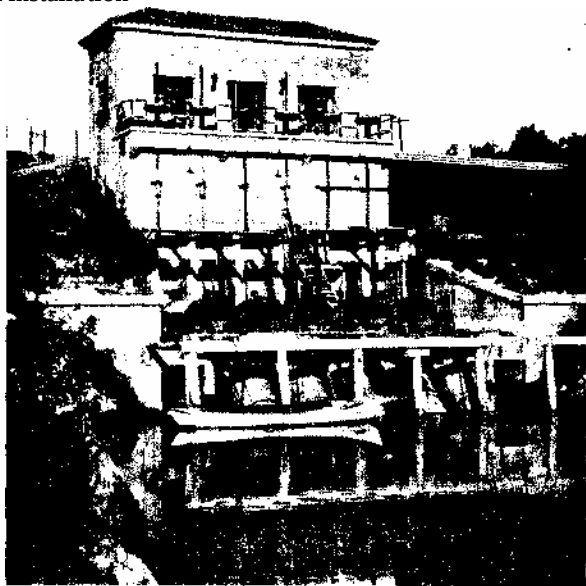


FIG. 119. Reclamation District 108 pumping plant, Woodland, California.

has been in charge of Superintendent A. E. Engbretson, who describes the construction work as follows:

"The tide-land has buried in it large amounts of logs and debris, especially in the older portions of the land. In digging, these are often met with and require considerable time in cutting. All logs should be cut entirely in two, even if partly below the

Tile-base. In deep ditches, such as required by the main, the tiles should be laid as soon as possible because of the fact that after a heavy rain the sides will move toward the center, thus making it very narrow. All tools should be sharp so as to cut the fibrous roots in the land.

"The tile-base is of such a nature that it is inadvisable to stand on it while laying, unless it be done promptly and in very dry weather. There is generally some water present; and any walking will make the base soft and uneven. It is also unsatisfactory to stand on the tiles while laying. This will cause them to be uneven and improperly placed. In order to avoid these difficulties, a plain board, 1 X 8 X 36 inches was beveled at one end, and a strap for the toe was nailed on top. When laying tiles, a person stood on this board and worked it back as the tile was laid. This left a smooth base on which tile could be properly laid.

"There are places in the tide-land that are very soft. These are perhaps old slough beds that have been filled. Tiles cannot be laid on this soft bed. A plank, 2 X 12 inches, is sunk below the tile-base so that it forms a solid, even base. Where these spots are not wide the ends of the plank should rest on firm ground. If they are wider, and two or more planks are necessary, blocks should be placed under the ends so that there will be no sinking. All places that are soft and seepy should be provided with planks underneath the tile-base so that there will be no settling below grade."

Recent experience in draining airports in similar soil has demonstrated the value of perforated, corrugated metal pipes which can be depended on to maintain a true grade and alignment in unstable trenches without extra precautions.

All tide-sloughs having water should be taken into consideration. For short, irregular tide-sloughs, a slab-drain can be employed. Rails and tussocks can be placed in old sloughs after which they may be plowed full. For all the main drains, where land is valuable, it will be cheaper in the long run to use tiles, even though a slab has to be laid underneath to keep the tiles in place.

Laying the Tiles — Tile-laying should begin at the outlet and proceed upgrade just as soon as the trench is finished to grade. A board or plank should be set under the tiles wherever the tile-base is in the least unstable, or where water is not salty, sections of corrugated metal pipe may be used. It is advisable to guard against obstructions and disturbance of the tile by blinding in each evening during construction.

Filling the Trench — After the tiles are blinded in, or partly hidden with loose earth, it may be desirable in fine-textured soil to cover them with a layer of rushes, straw, or sods, to facilitate the entrance of water into the drains. Rushes or sod placed over the tiles will be very slow to decay and will prevent the joints from filling up with clay or silt. The trench can then be backfilled by plowing off the sides with a plow equipped with long eveners, so as to allow one of the horses to walk on each side of the trench.

Details of Construction — Outlets should be walled up and screened, or, if liable to inundation, should be provided with a flap gate, counterweighted so it will close out a back current. Laterals should be brought into the main drain with a curve and a slight fall. Silt-basins and surface inlets should be 3 feet in diameter, so that a person may enter to clean them out, and should be covered or screened.

Sub-Irrigation — In open ditches or tile-lines, where it is desirable to provide sub-irrigation by checking the outflow for a couple of days every two weeks in the earlier part of the dry season, flash-boards may be provided.

Operation of Experimental System — H. R. Taylor, the former superintendent of the Astoria Branch Experiment Station, describes the operation of the completed portion of the drainage system as follows:

"Water-table — The difference between the effect of experimental laterals 380 feet long, and respectively 50 feet (Lat. B) and 100 feet (Lat. C) from their neighbors, was studied by means of borings or wells. Readings were taken during the last week in September before the fall rains. At that time the water-table was at a depth of more than 5 feet. Wells were bored to

a 5-foot depth. Readings were made, October 5, 1918, after a two-day rain, and on November 27, 28 and 29, during and after a storm period.

" *Weather.* — October 4 and 5, rain; November 25 and 26, rain; heavy showers during the week previous; November 27, frost followed by clear weather; night of November 27 and 28, heavy showers; November 28, cloudy; November 29, clear. In adjacent fields there was a considerable amount of water standing in pools on the surface. There was no water on the surface of the drained field. Data for November 28 will also apply with fair accuracy to November 26 and 27, as the outflow for those days was quite constant.

" *Yield.* — On the drained field, a crop of oat and pea hay yielded 5.1 tons to the acre. The best growth was made nearest the drains; and the plants were shorter and the number was less to the square foot, in proportion to the distance from the drains. Adjacent to the main drain, the plants reached a height of over 6 feet; at the point farthest from the main, a height of 4 to 5 feet. An undrained field of oats and vetch, adjacent to the drained field, approximately 2 1/2 tons of hay to the acre, but was a little **patchy on account of wet spots during the early spring.**"

Cost and Profit. — Cost of the tile system as described will average about \$25.00 an acre. The first crop, 5 tons field-pea hay to the acre, was double the yield on the portion not yet tiled. This crop was worth \$25.00 a ton at local prices, so that the cost of tiling was repaid in the first crop. Tiling will double the productive value of the greater part of the marsh lands in western Oregon. Much of this land is already provided with protecting dikes for main outlet ditches, but is in need of tile.

QUESTIONS

1. Describe the character of tide-land. Overflowed land. Peat-land.
2. Explain the general chemical composition of marsh soils.
3. What advantages do marsh soils offer as a field for reclamation?
4. What is a reasonable percentage of shrinkage in a peat soil?
5. Discuss points to consider in construction of a levee.
6. Describe the construction of a tide-box.
7. What are the main points to consider in designing a pumping-plant?

8. What factors enter into the total annual cost of pumping for drainage?
9. What are the main points to consider in designing interior drains for tide-land?
10. Give results of experiments relative to depth and frequency for underdrains in tide-land.
11. What is a suitable drainage coefficient for main tiling in tide land?
12. What is a minimum grade and size for lateral tiles in tide-land?
13. What precautions should be observed during construction to secure a firm tile-base?
14. How may sub-irrigation be accomplished in marsh soils?

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CHAPTER XX

THE DRAINAGE OF IRRIGATED LANDS

In the irrigated region, the chief types of lands needing drainage are (1) soils that are seriously alkaline in the virgin state, (2) those that are waterlogged or marshy in the virgin state, and (3) those that have become waterlogged and more or less alkaline as a result of seepage and losses connected with imperfect irrigation.

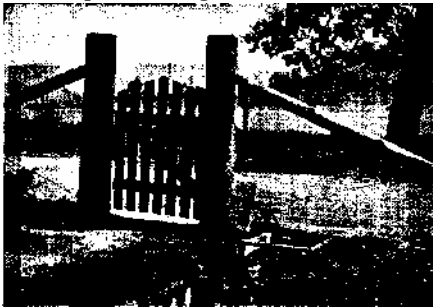


FIG. 120. Drainage water used for irrigation of lawn and garden.

The majority of irrigation projects face the drainage problem to some extent; and, on the average, not less than 20 per cent of all irrigated lands require drainage. On United States reclamation projects, 1,213,700 acres were irrigated in 1923 and it was estimated that 535, 807 had been reclaimed and protected by 1786 miles of drain

and that 132,084 acres were still damaged by seepage. Other projects where large areas have required drainage are to be found in the San Joaquin and Imperial valleys of California, the Pecos Valley in the vicinity of Roswell, New Mexico, the Yakima Indian Reservation, Washington and the San Luis Valley, Colorado.

There is a tendency for the third class of lands to increase in area throughout the lower-lying and finer-textured soils of the irrigated districts.

Why Drainage is Needed in Irrigated Sections. — Inasmuch as arid soils have not been subjected to leaching or development of water

veins, and have not had sufficient moisture to produce organic growth and consequent accumulation in the surface layers, the soil may be similar for a depth of several feet. The artificial application of large amounts of water with its attending losses eventually causes the water-table to rise. The presence of gravel or other porous layers may provide considerable natural drainage, but this is frequently insufficient. Hard-pan, when it exists, interferes with the movement of free water, often causing a local, high water-table. Arid soils usually contain considerable soluble mineral salts

and, when the water-table has approached within capillary range of the ground surface, evaporation causes these salts to collect there. They are commonly known as alkali, and may accumulate until they become detrimental to growth of cultivated crops, and alkali vegetation, such



FIG. 121. Trees killed by seepage in the Snake River Valley.

as salt grass and greasewood, is apt to appear in the affected areas.

Relation of Economical Irrigation to Seepage — The source of excess water is usually seepage from irrigation canals and laterals, deep percolation from wasteful irrigation, and surface waste water. It is possible to eliminate most of the percolation losses and surface waste by means of scientific irrigation, water being applied to the land without exceeding the useful water-retaining capacity for the root zone. During ten years of irrigation on the silt loam soils at the Oregon Experiment Station, no irrigation water has percolated below the 7-foot layer, as far as could be detected by soil moisture determinations. At the Umatilla Experiment

Station medium sand in lysimeters re-tained about $3\frac{1}{2}$ inches depth of

water for the 6 feet of soil, while silt soil in other lysimeters receiving the same amount of

irrigation, lost nothing by percolation. Light frequent irrigations and short runs with good control are necessary for the coarser soils.

More economical use of water is secured by using legumes and manures to build up and maintain the usable water-capacity and available fertility of the soil, and by practising crop rotation including occasional deep cultivation and a diversity of crops. These methods help to control transpiration and lessen



FIG. 122. Sweet clover on sulphured alkali land, Klamath, Oregon, 1917. (Courtesy Ore. Agri. Exp. Sta.)

the water requirement of crops. It has also been found helpful to practice rotation in the use of irrigation water and to base the maintenance assessments on the amount of water used. Less water is required when applied by proper methods at just the right time to well prepared land. The application of any needed fertilizer will also lessen the total water requirement.

Seepage from canals is a common source of excess water. Canal systems commonly lose 30 per cent in delivery. Farm laterals 1/2 mile long have been found to lose 15 to 20 per cent. As water becomes more valuable, clay puddle, heavy oil, or concrete may be employed for lining ditches. A loss of 10 to 15 per cent is perhaps justifiable for deep percolation and waste for fields devoted to general farming, where water is only moderate in price. Under economic conditions existing at present on many projects, the need for drainage is very apt to occur.

Drainage Practice in the West — Special methods are required for the drainage of irrigated lands and they are very different from those employed in the Central States. These methods were partly developed by the former Office of Experiment Stations, but most of the western experiment stations have contributed to our present knowledge of the subject.

In planning a drainage system for irrigated land, numerous

deep borings and a few test pits will be necessary. The water table will fluctuate considerably during the irrigation season, so that numerous carefully located observation wells will be helpful. The design will depend on many factors, the most important of which are: type of soil, topography, amount of irrigation water, runoff and source of damaging water.

Because of the alkali, the minimum required depth of the water-table is fixed by the range of capillarity, which is less for sandy soils than for other types. In fixing the depth of the drain, it should be remembered that the upward slope of the water-table away from the drain is considerable in tight soils, and allowance must be made for this. They should rarely be less than 8 feet in depth, and depths of 10 to 12 feet are frequently required, particularly for main drains. An effort should be made to locate them in the more porous layers of subsoil, if such exist at reasonable depths, since this will greatly increase their effectiveness.

The distance between drains may be relatively greater than in the humid sections, and depends upon soil and underlying formations. It may vary from a few hundred feet in tight soils, to over a mile where continuous formations of

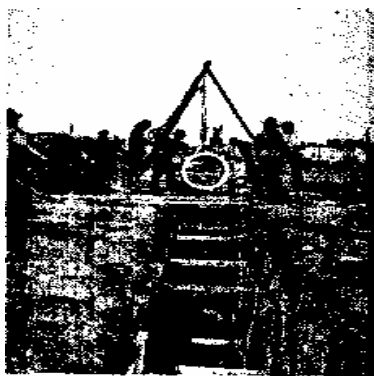


FIG. 123. Deep outlet drain installed in over-irrigated land, Snake River Valley.

open gravel are found. On flat areas of loam, parallel lines may be spaced 660 feet apart, and if underlaid with gravel, the spacing may be greater. Any important outlets should, of course, follow the natural depressions in the land. Wherever conditions will permit, intercepting drains, located near the upper edge of the affected area, should be used to gather water from higher

lands, and may relieve areas for as much as $\frac{1}{2}$ mile down the slope.

The required capacity of the drains will vary with the type of soil and the amount of water applied. A common rule is to

provide a capacity equal to $\frac{1}{3}$ of the irrigation flow to the contributing area.

This should be increased for gravel formations and decreased for tight soils. The maximum discharge per square mile in Yakima Valley varies from less than 1 second-foot for tight soils to about 2 second-feet for ordinary soils, and in gravel may exceed 7 second-feet. The Minidoka project drainage is reported to be 1 second-foot per 230 acres. Measurements on Shoshone project show a runoff of .47 second-foot, or 17 per cent of the irrigation water. The total runoff varies from

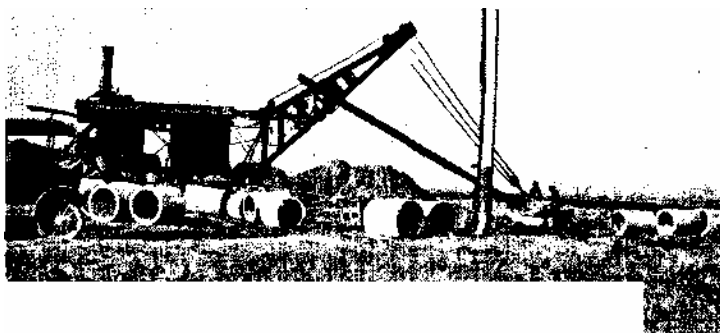


FIG. 124. Steam shovel rigged with long stick for trenches up to 20 feet in depth. Tile are thirty inch concrete, water mix, with three inch shell, and having four-foot lengths. (Courtesy Barr & Cunningham, Portland.)

less than 20 to over 60 per cent of the water applied. Closed drains are preferable to open ditches, where the volume is not too large, even if the first cost of the former is somewhat more. The size of the laterals should never be less than 5 or 6 inches. This subject is discussed more fully on page 178. Strong, well-made tile must be used. (See Chapter VI.)

The use of relief wells for tapping gravel formations where water exists under pressure is explained on page 105. Small relief wells, closely spaced, have been employed in the drainage of lands underlaid with more or less broken shale formations, such as are found in sections of Colorado. They have also been used successfully on the South Side Twin Falls Project in Idaho,

where water exists under pressure in the underlying lava rock formation. Six-inch wells are put down with well drills, and they usually are connected with closed outlet drains. Vertical drainage downward may be possible in some formations and is described on page 50.

Drainage by pumping from wells is now being developed and will be described in the next chapter. This method is employed where soils which do not respond readily to ordinary drainage are underlaid with porous strata which can be reached by wells, where power is cheap, and where the value of irrigation water is high and the pumped water can be used.

Much of the seepage water from any drainage system may be used again for irrigation of land in the lower parts of the valleys, particularly when diluted with other water. Occasionally, water is pumped directly into the irrigation-laterals from the drains. In time, a combination of natural and artificial drainage, together with more economical use of water, will contribute greatly to the development of highly profitable and stable agriculture under irrigation.

The deep trenches required in the drainage of irrigated land are subject to caving, especially in water-logged soil, and shoring or tight sheeting may be required during construction. Trenching machinery may have to be provided with shields, but is not successful where a very soft bottom is encountered. Under this condition, bedding the tile with gravel is usually necessary, or special pipes may be used. The drains should be rapidly



FIG. 125. Concrete manhole and cover. Upper part of manhole built of pipe sections. (Courtesy Barr & Cunningham.)

constructed a short section at a time, proceeding from the outlet. Manholes with silt basins may be needed at intervals, in the finer textured soils, for cleaning out silt and roots. Suitable outlets and other structures necessary to the proper care and maintenance of the system should be constructed. Care must be taken to refill the trench completely. The construction of open drains is discussed in Chapter XVI.

The cost of closed drains, 8 feet deep, varies from \$0.60 to over \$1.00 a foot, the lower figure being for small tile in good ground



FIG. 126. Building a drainage ditch with water and a scarifier.

and the higher figure for larger tile or difficult construction in unstable soils. The number of lines employed makes the cost vary from \$10 to over \$50 per acre, with the average about \$30. Cooperation is usually necessary in draining irrigated land, and the cost is lower on larger districts. A man's land may be injured by careless use of water on higher lands. The District Drainage Law of some states, in apportioning the cost of drainage, provides for assessment of contributing damages against higher land and ditch owners. The character of the soil must be such that the drains will operate. Then, too, general economic conditions must be considered in determining the feasibility of a project. Some of the alkaline greasewood lands at the higher elevations, or remote from outlets, and having fine-

textured impervious subsoils, have not yet proven amenable to drainage under normal conditions.

Treatment of Irrigated Lands After Drainage. — Wherever possible, at reasonable cost, alkali land should be leveled into regular or contour checks after drainage, and submitted to copious flooding with water of good quality which will entirely cover the surface. Should any high spots be missed, alkali is apt to concentrate on these unflooded summits. Water should leach through all the land and be kept passing downward. During reclamation, the incorporation of organic matter is desirable in order to restore the structure of the soil, and protect the surface. Manure and sulphur, calcium sulphate or other sulphates will be needed for black alkali and help to keep sodium salts in solution so they can be leached out. In this way, calcium will be brought into solution and lessen the tendency to puddle. Sweet clover may then be established by keeping the surface moist and the alkali dispersed until the crop shades the ground. This crop will add humus and loosen up the soil below the plowed depth, thereby facilitating drainage. Blue grass and ladino clover pasture with copious irrigation have been used to improve alkali conditions. Several years are often required for reclamation.

The Carmel Drainage District, Conejos County, San Luis Valley, Colorado, contains 5040 acres. It was completed in the fall of 1914 at a cost of approximately \$11 per acre. The subsoil was coarse sand and alluvial gravel, and the drains were spaced $\frac{1}{2}$ mile apart. Prior to drainage, only

1330 acres could be cultivated at all, and the remainder of the land was worth nothing except for the appurtenant water right which was valued at \$15 an acre. The first season after drainage, 1300 additional acres were placed under cultivation and the crop receipts from this, and from the land that was already being cultivated, were more than sufficient to pay all of the cost of the drainage system. By 1922 practically all of the district was back in cultivation, and the average value of the land was about \$125 per acre, according to D. G. Miller, U. S. Bureau of Agricultural Engineering.

On the East Grand Plains Drainage District, Chaves County,

New Mexico, the owner of a 320-acre tract stated that, prior to drainage, his land was worth but little, that much of it would not grow anything, and that eventually it would have been abandoned. The cost of the drainage system later installed was approximately \$13 per acre. The land responded slowly after drainage, but finally became capable of producing 4 tons of alfalfa per acre, and the owner now values the land at about \$200 per acre, according to L. T. Jessup, U. S. Bureau of Agricultural Engineering.

Wild Marsh and Meadow Reclamation. — The marsh lands of the intermountain region include wild hay meadows of dark silt loam, or peaty silt loam and tule beds (bulrushes), growing on peat. These soils are, as a rule, readily drained, though in some cases supplemental pumping is necessary. A layer of chalky material, more or less diatomaceous, is frequently found, but the fifth or sixth foot is usually medium sand which facilitates underdrainage. With water fairly well controlled on these marshes in experiments by the Oregon Station, it has proven practicable to substitute domestic grasses and clovers for the wild hay, and to double the former yield with less than half the amount of irrigation that is ordinarily employed on the wild meadow.

The tule marshes may be burned over when wet underneath, so that the soil is not destroyed. This removes the heavy mat of large vegetation, provides some available plant food, helps to neutralize any acidity, and makes phosphorus more available. Such land as that in the Klamath region is usually plowed rather shallow the first year, and cropped to oats for hay, 3 or 4 tons an acre being realized. After one or two crops of grain, the land is seeded to Alsike clover and timothy, which yields 2 to 3 tons an acre. On one cooperative experimental tract of 1000 acres of diked marsh land in that section, there was pumped off an acre-inch an acre in early spring, and later in the season 10 acre-inches an acre was pumped onto the tract for irrigation.

Leaching Experiments with Saline Lands. — During the period 1901-1906, the United States Bureau of Soils made a

number of experiments in several states with regard to leaching alkali. A 40-acre tract of saline land or "white alkali" near Salt Lake City was tilled, checked and flooded. In September, 1902, before flooding, the upper 4 feet of soil contained 6651 tons of mineral salts. After applying 410 acre-feet of water, there remained in October, 1904, only 878 tons of salt.

In 1913-1914 the Drainage Division of the United States Department of Agriculture made similar experiments in Boise Valley, Idaho, and in Grand Valley, Colorado. On 23 acres of the Boise Valley tract, the upper 5 feet of soil contained 753 tons of alkali. During irrigation the first year, the water applied carried 0.54 and the drainage water carried 2.59 tons of salt per acre-foot. During the first year, soil analyses showed that 150 tons of salt had been removed.

The experimental tract in Grand Valley contained 10 acres. Soil analyses of the upper 6 feet of soil showed that the surface foot contained 3.29 per cent of alkali, and that the lowest percentage



was 2.12 in the third foot of depth. Tile-lines and contour checks were constructed and the tract flooded continuously during two irrigation seasons. During the first season the alkali content of the upper 6 feet of soil was reduced by 1314

FIG. 127. Drain 11 feet deep, built by sluicing, Alkali Experiment Field, Vale, Ore.-gon. 1922.

tons. The alkali in the surface foot was reduced by 75 per cent. This tract is now producing about 4 tons of alfalfa per acre.



FIG. 128. Flooding to remove soluble salts in alkali land reclamation. Experiment Field, Vale, Oregon.

Reclamation Experiments with " Black Alkali " Land. — An experiment is under way near Vale, Oregon, where 1500 pounds



FIG. 129. Rye at right one year after drainage of alkali land, where 500 pounds sulphur and 10 tons manure per acre had been applied; check at left had some cultivation, and irrigation, but no chemicals. (Courtesy Ore. Agri. Exp. Sta.)

an acre of sulphur has been used successfully in connection with bulky nitrogenous organic manure to improve native " black

alkali" soil and facilitate laundering alkali out. With such treatment over 50 per cent of the black alkali has disappeared and good crops of alfalfa have been grown. The outlet ditch has been very economically built by a sluicing process. Numerous resistant forage plants have been used and afford fair returns there during reclamation (4).

Avoid Alkali Accumulation by Prompt Drainage. — It is possible, then, to reclaim much of the land affected by alkali. Where the concentration of sodium salts is low, the soils open



FIG. 130. Sweet clover established on alkali land after two years' treatment with sulphur and manure. (Courtesy. Ore. Agri. Exp. Sta.)

and porous, and the drainage systems efficient, it is not a difficult task; but with close tight soils which have become puddled with black alkali (sodium carbonate), and where the percentage of salts is high, it is a difficult and expensive undertaking, requiring years of work before there is much return. The best method is to prevent the accumulation of alkali by draining early. Every district and each farmer should watch the water-table closely, and when it has approached within capillary range of the ground surface, install a drainage system. Farmers should not be deceived by the increased yields, without much irrigation, which result when the water-table first approaches the surface. This condition usually precedes serious damage.

Construction costs are often very much less where drains are installed before the soil has become completely water-logged, and early drainage will often prevent several years loss of crops due to alkali. The irrigator should realize the necessity of preventing injury to the land, and irrigated lands must be



FIG. 131. Alfalfa established on reclaimed alkali land on the left vs. virgin alkali land on the right, Experiment Field, Vale, Oregon, 1929.

drained at the first sign of damage. Delay in this matter is criminal negligence and will result in very serious losses to the whole community.

QUESTIONS

1. What three classes of land in the arid regions need drainage?
2. Why is drainage of irrigated lands acquiring greater importance?
3. Why is it necessary to drain irrigated land promptly when needed?
4. Describe wild meadow lands, giving their nature, vegetation, and crop adaptation with water controlled.
5. What peculiarities of arid soils affect percolation and drainage?
6. How should drainage qualities of arid subsoils be studied?
7. What is a good average depth for underdrains in irrigated land?
8. How far apart may drains be placed, if of average depth, in irrigated land?
9. What factors affect capacity of underdrains in irrigated land?
10. Why do lateral tiles need to be fairly large in irrigated land?
11. What treatments help to improve alkali land after drainage?
12. Give an example of successful underdrainage of irrigated land.

13. To what extent may artificial drainage be assisted by economical use of irrigation water?

14. How may the feasibility of the reclamation of alkali land be determined?

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CHAPTER XXI

DRAINAGE BY MEANS OF PUMPING FROM WELLS

It is a well known fact that, on all irrigation projects of any extent, the rise of the ground water-table in the lower lying lands has resulted in water-logging and accumulation of alkali, and has rendered unfit for agricultural purposes large areas which formerly because of location, topography, and soil were among the most desirable lands on the project. Factors contributing to this water-logged condition are seepage losses from canals located on higher areas, and the use of excessive amounts of water in irrigation.

Development of Well Drainage — Some 15 years ago Murphy (7) observed that shallow irrigation wells lowered the water-table in the vicinity where located, and suggested the use of wells for drainage. On the Salt River Project in Arizona this condition obtained. The water-table near the wells was 12 to 15 feet lower than in remote districts of similar topography and elevation. In addition, there was need for any additional water that might be developed by pumping, so it was not difficult to put the matter to a test on an extensive scale. The effectiveness of such a limited number of pumps lowered the water-table in the Arizona Valley, and led to widespread interest and application of the method there a decade ago. Prior to the installation of pumps for drainage, the ground-water had risen an average of 1½ feet per year for 7 years, and as construction of open ditches on part of the project had not been effective, the efficiency of the pump in comparison was very noticeable.

During the past decade, this well drainage method has been extensively tried in the south San Joaquin Valley, where in 1929 some 60,000 acre-feet of drainage-water was pumped and used for supplemental irrigation. The engineer in charge advised

that the capacity would be increased to 80,000 acre-feet for the succeeding year. This method has also been applied in Texas, the Pioneer Irrigation District in Idaho, and in certain valleys in Oregon.

Advantages of Well Drainage. — Several advantages of pumping for drainage as compared with the open ditch method have been recognized as especially applicable to the irrigated waterlogged sections, viz.:

1. The ability of pumping plants to lower the water-table to a greater depth than can be usually secured by gravity methods.

2. The lower initial cost per acre over gravity systems of covered tile or open ditches. Tile-lines in irrigated lands should be 7 to 12 feet deep. The initial cost of gravity drainage will run about twice that of deep well pumping where conditions permit use of the latter.

3. It makes available a supplemental supply of irrigation water where the gravity supply runs short late in the season. Where this is the case, there is an inducement to keep the pumps operating and the water-table lower. This market for the water for use on nearby irrigable land frequently meets the cost of maintaining the system, or even the total cost.

4. The flexibility of the system is important. Additional pumps can be installed as needed. Other pumps can be moved without great loss in investment.

5. Pumping plants have a permanent effectiveness, whereas open ditches are inclined to fill up with silt and vegetation, with loss of depth.

6. There is a saving of land and the elimination of unsightly soil banks which accompany open drains on large projects.

Among the disadvantages of the method are the expense involved for the smaller owner, lack of information as to geological formations, and danger of neglecting the pump.

The aim of such a method of drainage is to lower the ground-water in the whole locality, and it is best suited to district use. Irrigation district laws in most western states permit them to engage in drainage activities. Differences may occur in different sections (1) as to need for water for irrigation or other purposes,

(2) as to the minimum required drainage depth, depending somewhat on the crops grown, and (3) in natural conditions and general need of drainage.

Quantity to be Removed— If it is estimated that free water occupies 30 per cent by volume of the saturated soil area where the volume to be unwatered is known, an estimate of the quantity of water to be taken out can be made. The aim should



FIG. 132. Stovepipe well casing and "starter" used in constructing well for drainage. (Courtesy J. C. Marr, U. S. Bureau of Agricultural Engineering.)

be to lower the water-table to a point beyond the reach of plant roots.

The *specific capacity* of a well is denned as the volume of water which it will furnish in a given time for an even unit of drawdown in the water-table during pumping. The unit used is usually cubic feet per second or gallons per minute per foot of draw-down, the latter term referring to the lowering of the water-table near the well during pumping.

Fundamental Requirements — Professor W. W. Weir, of the University of California Experiment Station, has made an exhaustive study of the subject of pumping for drainage, and has listed the following fundamental requirements for success:

1. There must be a direct connection between the ground water-table near the surface and the deeper underlying water-bearing strata from which the water is pumped.

2. The underlying water-bearing strata must be porous enough to give up water freely under pumping.

3. There must be enough water pumped in the lower strata to cause that which is near the surface to move downward by gravity to replace that which has been pumped.

4. The general effect on the water-table should be the same whether the water is pumped from the bottom of the reservoir or taken from near the top by means of tile or open drains.

Well Location and Construction. — In a given locality where there is deep alluvial filling, the well can usually be located at any convenient point on a given section of land or farm. Where water-bearing material is present, it will probably extend

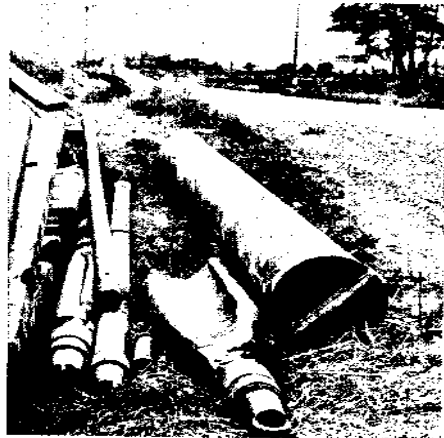


FIG. 133. Bailer, spud and jars. (Courtesy J. C. Marr, U. S. Bureau of Agricultural Engineering.)

underneath the whole area. The method of development is to drill with a heavy well-driller by means of hollow tools, armored at the-bottom and containing a flap valve capable of picking up gravel a few inches in diameter which would have to be pulverized by solid drills before it could be removed. This also gives a better chance to observe the formation pierced in drilling the well, so that a better well log or record of the formations encountered can be secured. A popular size

of well is 16 to 18 inches in diameter. The depth of drainage well usually ranges from 100 to 250 feet. The casing employed is usually of the



FIG. 134. Driverhead and bailer.

stovepipe type, 2 ply, 10 or 12 gauge material, with 3 ply or heavier construction at the starting point, which begins with a steel starter. For larger wells, the casing is usually forced down by means of hydraulic jacks. The joints in the inner and outer courses of casing alternate, and may be welded or united by

striking the casing heavy blows with a pick. After a good water-bearing layer has been traversed, this casing is slitted throughout the water-bearing strata shown by the well log



FIG. 135. Hydraulic jacks for starting well casing, and casing perforator. (Courtesy J. C. Marr, U. S. Bureau of Agricultural Engineering.)

record, by means of a perforator, consisting of a heavy blade on a hinge which is forced against the inside of the casing by the well-driller. Such a well can usually be developed to larger

capacity by alternately stopping and starting the pump used in development, so as to loosen and pump out much of the finer material in the water-bearing layer. Where only fine material is encountered, a patent strainer may be employed.

How Water Enters the Well. — When water is pumped from a well, the water surface in the well stands lower than that in the surrounding soil. The amount of this drop is called draw-down. The slope of the surface of the subsoil water is toward the well. When the water in the latter has been lowered by pumping, water in the surrounding water-bearing material flows toward the well. The more the water is pumped out, the greater will be the draw-down which flows toward the well. The draw-down will be greater in fine than in coarse soil material. Comparative tables have been compiled from which one can estimate the capacity or size of the pump necessary to yield a given flow or to lower the water-table a definite amount. The more water it will yield for a given draw-down, the better the well and the more economically it can be operated. It is desirable to obtain a well of good capacity.

Pumping Equipment. — The modern deep well or turbine type of pump is suitable for drainage pumping. Where electricity is obtainable, it should be connected directly to an electric motor mounted on the pump head. There are several standard makes of pumps. The discharge can be at the surface or below the surface. It will usually be carried into a surge tank or settling basin with an air vent or standpipe, and then carried into an irrigation system. Adequate housing should be provided. Wells of 1 to 3 cubic feet per second capacity may be installed and equipped for the depth indicated at a total cost of \$1500 to \$4000. The Oregon Agricultural Experiment Station has recently developed three wells of this type which discharge approximately 2 cubic feet per second where the depth has been of the order of 100 to 150 feet. The cost has been approximately \$3000 for each unit.

Use of Drainage Water. — The discharge from a tile drain is not generally utilized. On account of the cost of pumping, there is a tendency to pump as small a volume of irrigation as

possible for beneficial use. One important use of drainage water is to supplement the gravity supply of the project.

Pump drainage water can be used to advantage in the sandy irrigated areas with mutual benefit. The water drawn from considerable depth is usually of fairly good quality and may frequently be pumped into irrigation canals so that it mingles with the general water supply of the project.



FIG. 136. Drainage well which yields six second-feet, Pioneer District, near Caldwell, Idaho. (Courtesy J. C. Marr, U. S. Bureau of Agricultural Engineering.)

Pumping vs. Other Types of Drainage. — The cost of drainage varies with soil type, water supply and other local factors. The difference between pumping and other drainage lies in the operation charge, which is the determining factor of the cost and the feasibility of pumping over other types of drainage. The total annual cost of drainage is the basis upon which comparison may be made between pumping and gravity drainage. The first cost of pumping will frequently be less; the operation cost possibly more.

The Economic Limit of Pumping for Drainage. — The pump ing for drainage from wells has an economic limit, and efficient operation must be obtained in order to be successful. Feasibility will depend upon a number of factors the chief of which are:

1. Lift.
2. Supply of energy.
3. Length of pump ing.
4. Extent to which water can be used for supplemental irrigation.
5. Efficiency of the plant.
6. Yields.
7. Value of increased yields due to drainage.

The cost of pump ing increases with the amount of lift. The cost of fuel varies almost directly with the lift, and the total cost increases proportionately. If the cost is twice as much for one lift as for another, then the production

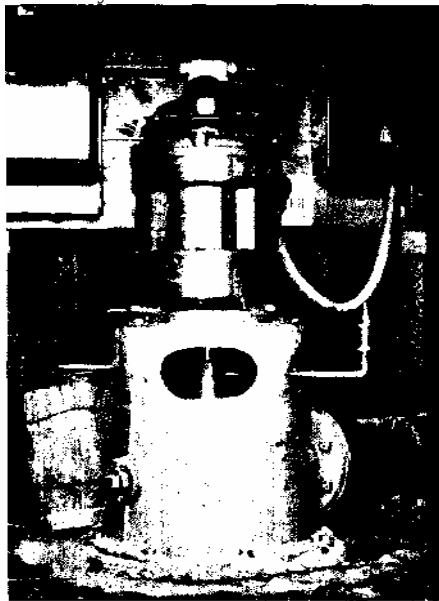


FIG. 137. Turbine pump head with electric motor, Lodi, California.

per acre must be over twice as much to warrant the latter undertaking.

The length of time necessary for keeping the pump in operation each year depends upon the depth at which it is desirable to keep the water-table and the depth of the root system of the crop. In Salt River Valley, continuous pumping has been practiced for 300 days. In Merced District, California, it is 270 days. In general, the drainage season will coincide with the irrigation season.

Where all the drainage can be used for irrigation, the irrigation and drainage will both share the expense of the pumping.

Plants should be operated to make the utmost use of power rates by private companies. On some government projects, cheap power may also be available. There will be a distinct advantage, if payment can be made by careful correlation of the speed of the pump to the head under which it is operated.

The increase in yield and value of crops obtained by successfully lowering the water-table by pumping has a marked effect upon the economic limit of pumping for drainage. With increase in yields of high-priced crops, the returns realized may be sufficient to warrant such expenditures in drainage enterprises.

The success of drainage by pumping from deep wells seems to be largely dependent upon economic conditions. If pumping can be done in connection with supplemental irrigation or other remunerative use, or by the cost of operation shared only incidentally by drainage, then the construction of this type of drainage system will be economically feasible.

QUESTIONS

1. What are the fundamental requirements for successful well drainage?
2. What are the advantages of pumping by means of wells?
3. Why is it important to keep the log of the well when installed?
4. In what way is a report by a ground-water geologist desirable in the development of well drainage?
5. How does water get into the well?
6. What is meant by the "stovepipe" type of well? By "draw-down"? By "specific capacity"?
7. What type of pumping equipment should be employed for drainage?
8. What factors determine the economic limit of pumping for drainage?

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CHAPTER XXII

PREVENTION AND CONTROL OF EROSION, WITH SPECIAL REFERENCE TO TERRACING

Soil erosion has been a problem in the United States since the beginning of extensive farming operations. Large areas in the more humid sections have been completely denuded, and have lost their agricultural value. Even in dry farming sections, the reduction of the organic matter, by the combination of wind and water erosion and cropping, has led to very serious soil damage.



FIG. 138. Eroded land near Goodman, Mississippi. (Courtesy U. S. Bureau of Agricultural Engineering.)

According to H. H. Bennett of the U. S. Bureau of Chemistry and Soils, billions of pounds of plant food are removed from the land surface each year. The removal is estimated at twenty times that taken by crops in the United States. The loss is not confined to the rainy regions. In the grazing regions, overgrazing reduces the organic matter and native vegetative cover, and the torrential showers which occur in warm weather do enormous damage.

The silt removed from the hillside accumulates in expensive

reservoirs, artificial drainage channels, or navigable streams, where it may be necessary again to move it.

Causes and Factors Affecting Erosion. — Some conditions that contribute to soil losses by erosion include (1) clearing of steep hillsides, (2) over grazing, (3) careless till- (4) heavy downpours, and (5) neglect of sloping land.

Erosion may cause damage due to two processes — the first known as sheet erosion, the second as gullying. Sheet erosion is the gradual movement of surface soil down the grade. Around a given contour, the

movement of soil to a lower level would be approximately uniform. Gullying is the process whereby soil is removed in fairly definite

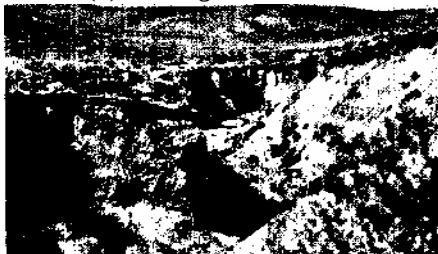


FIG. 139. Gullied land under annual precipitation of approximately 10 inches, Southeast Oregon.



FIG. 140. Eroded range land, under 10 inch precipitation, Southwest Idaho.

channels, which will vary in size from diminutive rivulets to enormous washes of indefinite dimensions.

If all the water which falls on a given area of land could be

absorbed there would be no erosion. It is the water which flows over the surface that does the damage, and it is that part which should be controlled. Soil high in silica in relation to iron and aluminum is most subject to erosion. The amount of erosion will increase as the water moves down the slope, be-cause of the increased volume of water, and because, as the water picks up material, its aggrading action is much greater.



FIG. 141. Eroded hillside in "Palouse" region, Southeast Washington.

Control. — The control of erosion is dependent on several factors:

1. The velocity of water must be reduced so that it will be unable to carry an appreciable amount of soil.
2. The surface of the soil must be protected as much as possible.
3. The absorptive capacity of the soil for water must be maintained.
4. Control measures should be prompt before gulying begins.

The methods to fulfill these conditions will include:

1. Keeping steep land permanently in grass or forage.
2. The use of vigorous rooted cover crops, such as sweet clover.
3. The use of an organic matter covering or mulch.
4. Deep contour plowing to increase absorptiveness.
5. Terracing to retard the flow of water and keep it spread out.
6. Tile underdrainage to improve absorption and removal underground.

These methods will be effective for controlling sheet erosion. Gullying is controlled by the following methods:

1. Employing various kinds of dams to dam the gullies.
2. Using tile and surface inlets.
3. Keeping drains grassed over by skip plowing, as the soil is "safer under the sod."
4. Employing strip farming by planting strips of sweet clover or other pasture plants in bands across the steeper slopes.
5. Using underdrainage and inlets or rip-rapping the surface run with rocks.

Terracing. — The terrace is in effect a channel constructed around the hillside following the general contour in such a way as to conduct the surface waters from the hillside without excessive erosion.

The vertical spacing between terraces and the slope, in order of importance depends upon:

1. The slope of the hillside.
2. The intensity of rainfall.
3. The character of the soil.

Terraces are used to reduce the velocity of the water to a point where the amount of soil material it will carry will be negligible. Terraces may be unnecessary on land having a slope of less than 2 to 4 feet in 100. They are not practical on land having a much greater slope than 15 feet to the hundred. Terraces are laid out to correspond roughly to the contour of the field.

Design and Construction of Terraces — The vertical distance between terraces should vary from 3 to 5 feet or more. The horizontal distance will vary with the slope. Terraces are built with a plow and a grader, or with special implements, after being staked out with a surveyor's level, by setting stakes every 25 or 50 feet along the contour, or at points of equal elevation beginning at the top of the field. Each embankment should be 1 to 2 feet high and 15 to 25 feet wide, to avoid interfering with farming operations. The length of the terrace can be as great as 1/2 mile, yet it is always desirable to construct them as short as practicable. The effectiveness of the terrace depends

upon its ability to convey the runoff without causing excess washing. This is accomplished by controlling the velocity, and the amount and course of the runoff by the grade and slope of



FIG. 142. Rice fields on terraced land, Philippine Islands, 1920. (Courtesy U. S. Bureau of Agricultural Engineering.)

the terrace channel. The terrace channel should be so constructed that the water moves in a thin sheet at a low velocity.

The terrace should be laid out so that the channel will discharge

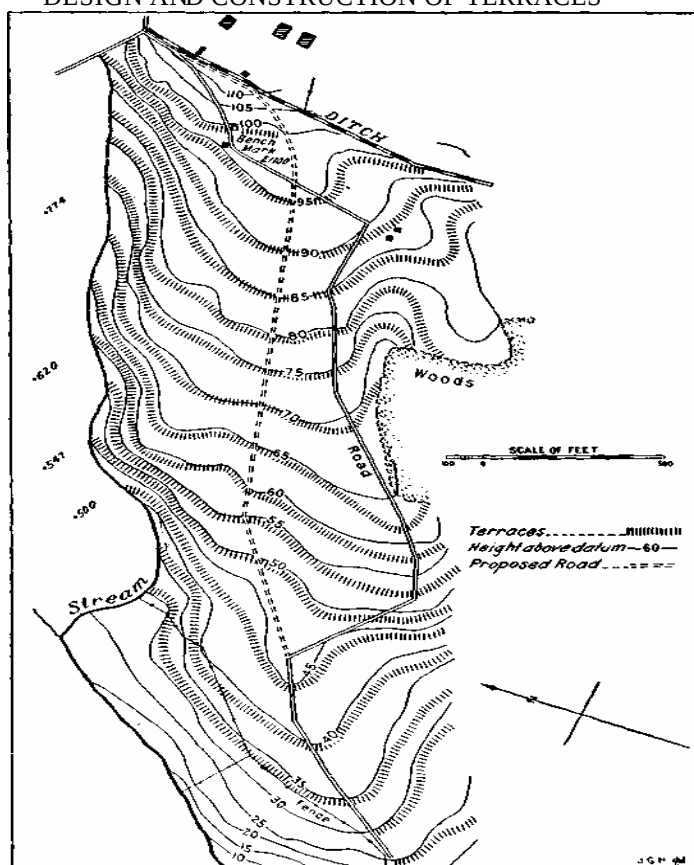


FIG. 143. Arrangement of terraces for farm. (Courtesy U. S. Bureau of Agricultural Engineering.)

charge into a natural stream or constructed surface run. The channel should be protected with some type of lining or by the construction of a sufficient number of drops or checks. The cost of terracing with plows and scrapers, such as a V grader, may run from \$2 to \$10 an acre. There is no universal method; selection must be made that will be best suited to local conditions. The terrace channel may be flatter in the upper part



FIG. 144. View of completed terrace. (Courtesy U. S. Bureau of Agricultural Engineering.)

and have a maximum fall of about 6 inches per 100 feet. Curves have been prepared for terrace channel grades (13).

Control of Gullyng — Gullyng is best controlled by proper preventive measures. Properly terraced land will not gully. Terracing should take place before farming operations are started. Where gullyng has started, control is expensive, but it may be accomplished by the use of soil-saving dams. A stream will become overloaded if its velocity is checked, and when it is so overloaded, deposition will take place. Dams may be made of straw, brush, earth or concrete. The dams should have a good footing, particularly where masonry is employed.



FIG. 145. Front view of home-made terrace drag, in operation on tobacco farm near Summerdale, Baldwin Co., Alabama. Note galvanized iron face on cutting blade of drag. (Courtesy U. S. Bureau of Agricultural Engineering.)



FIG. 146. Owensboro ditcher. (Courtesy Owensboro Ditcher & Grader Co.)



FIG. 147. Owensboro terrace grader. (Courtesy Owensboro Ditcher & Grader Co.)



FIG. 148. Series of concrete soil-saving dams in roadside ditch. (Courtesy U. S. Bureau of Agricultural Engineering.)

There should be an adequate flood-way. A siphon arrangement leading through the dam will allow the load to be deposited and the clear water drawn off and to pass through the dam, from above the silt on the upstream side to the bottom of the channel below the dam. Old fence posts may be set a

cross the stream and pieces of old woven fencing placed upon them at intervals of 4 or 5 feet in vertical elevation along the channel. Brush and straw may be placed in front of these fences to check the silt and restore the soil. It is necessary to make provision to handle the worst rain or heaviest storm.

Maintenance. — The Federal Farm Land Bank of Houston, Texas, requires that rolling land be terraced as a condition for contracting loans. This is because the terraces save the soil, conserve moisture, and increase yields. Careful attention must be given to inlets and to crossings, where the terrace encircles draws. Plantings should be parallel to the terraces. The plowing

should be done so as to reinforce them. Constant attention is needed for the maintenance of terraces, especially when new.

Erosion Experiments. — Studies in Missouri show that in from 29 to 73 years, 7 inches of soil is removed from land having a moderate slope, depending upon the culture or vegetative covering. At the North Carolina Experiment Station, land

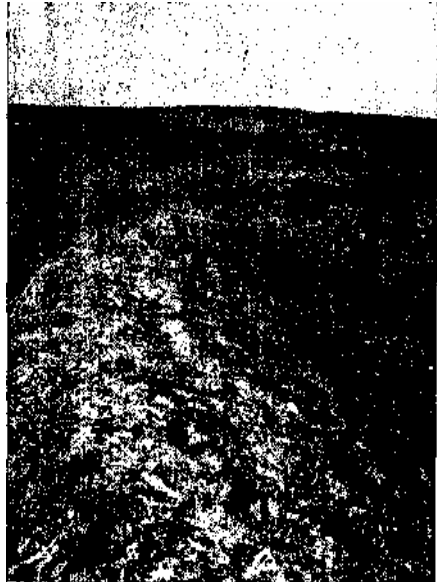


FIG. 149. The two men in this picture stand where there was formerly a gully 9 feet deep. Field restored to profitable cultivation by terracing. North Carolina State College Farm, West Raleigh.

sodded with grass was found to hold back 416 times more soil than bare ground, and 213 times more water than the soil of untterraced cultivated land. At the Experiment Station at

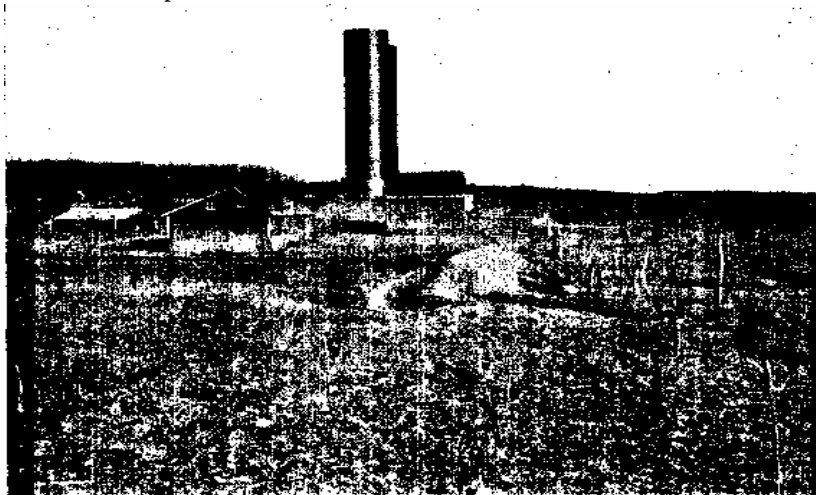


FIG. 150. Soil-saving dam made of earth. Note silted fill above dam, and surface ditch for overflow. (Courtesy U. S. Bureau of Agricultural Engineering.)

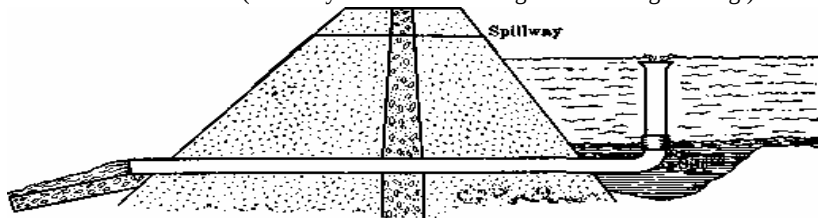


FIG. 151. Dam and relief siphon to prevent gulying and catch silt. Waste materials of the farm such as brush, or woven fence stretched on stub posts, may be effectively used in building small soil-saving dams.

Spur, Texas, land sloping only 2 feet in a hundred, with 27 inches of rain in a year, lost 40 tons of soil and 44 per cent of the runoff.

Nature and Moisture Content of Soil. — Tillage, intensity of rainfall, vegetative cover and steepness are found to affect erosion. Terraces in semi-humid regions are beneficial in conserving

moisture. It is reported that 2,500,000 acres were terraced during 1930. A number of new erosion stations have recently been established, where strips of land having different slopes or terracing treatment or surface covering will be carefully studied as to the amount of water-soluble and the solid material carried on at the lower end. Careful



FIG. 152. Sweet clover in use to check erosion where tile were too small and washed out.

measurements and analyses of rainfall and runoff are made. These studies will yield more exact information as to the effectiveness of different treatments for conserving soil against erosion.

QUESTIONS

1. Describe the extent of soil loss due to erosion.
2. What factors contribute to or favor erosion losses?
3. What measures can be employed to check sheet erosion?
4. Describe the construction of a soil-saving dam.
5. Describe the procedure in laying out a terrace with the aid of a level.
6. What tools are used in constructing terraces?
7. What points should be included in the construction and care of constructed terraces?
8. What cultural operations will aid in checking erosion losses and in increasing absorptiveness of soils?
9. What is the suitable vertical distance between terraces?
10. What is a reasonable grade for terrace channels?

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CHAPTER XXIII

MISCELLANEOUS DRAINAGE PROBLEMS

Besides the drainage of agricultural land, there are a number of special drainage problems in connection with district drainage which need attention. Such problems are, for example, the drainage of barn yards, the drainage of ~ buildings, lawns and gardens, the disposal of sewage effluent from septic tanks and sewage filters and the drainage of public and private roads. a barnyard, there should

Drainage of Barnyards. —

For draining be a dike, a ditch, or a tile-line around the farmyard to shut out any water that might otherwise run in from the outside, because half the battle in any drainage project is to divert the water before it gets on the land. The feed-floor in the barn yard should slope gradually to a catch-basin which carries the water

below. Water from the eaves should be collected and carried through a "down spout" to a catch-basin. This basin should be large enough to take the water and allow the silt to settle. The inlet should be protected by a grating. Under-drains may be used as in field drainage; but they will usually

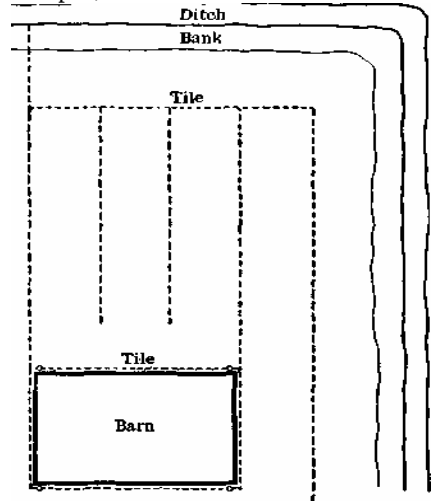


FIG. 153. Plan of drainage system for barnyard.

prove less effective in barnyards on account of the puddling action of the stock in muddy weather. Tile-drains, if used, should be placed $2\frac{1}{2}$ feet deep and 2 rods apart, and the trench filled with gravel, after which the yard should be graveled.

The Drainage of Buildings, Lawns, Gardens, and Golf Grounds. —

There should be a drain leading from all basements; and the basement of each substantial farm building should have a drain-tile laid just outside the base, a few inches below the lowest point of the foundation. lawns, golf

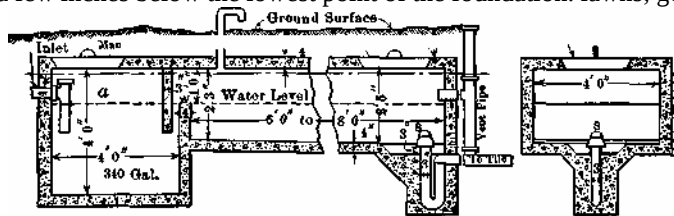


FIG. 154. Plan and sectional drawing of a septic tank.

grounds and gardens in wet climates will be benefited by underdrainage. Intensive truck crops will often justify very thorough drainage.

Orchards. — Orchards affected by excessive water and erosion also require tiling. The tile-drains should run in the center of the spaces between trees, as far from the trees as possible. Where seepage-water occurs throughout the season, fairly deep drainage is best for trees, and also prevents the tree roots from reaching the drains. Relief wells are often useful. Seepage should be intercepted.

Septic Tanks and Sewage Disposal. — In some states, it is unlawful to discharge raw sewage into running streams. It is, therefore, necessary that sewage from rural dwellings and other

buildings be rendered sanitary before it is discharged into running water. This can be accomplished most economically by means of the septic tank and the absorption system. The septic tank is merely an underground tank into which the sewage is discharged and allowed to undergo natural chemical and bacteriological changes for a period of eighteen to thirty-six hours, after which it can be discharged into the absorption system.

Sewage Disposal. — A septic tank of average capacity properly located and constructed may cost approximately \$100, and should protect the farm water supply and the health of man and livestock. Having air and sewage in a finely divided state favors decomposition. A tight underground septic tank with shallow distribution of the effluent in porous soil is regarded by Warren (9) as generally the safest and least troublesome method of treating sewage upon the farm. It permits some irrigating or manurial value to be realized. Such a tank permits mineralization of the organic matter. The purification is further advanced by filtration of the effluent through well aerated soil. Locate the tank in an isolated place below and away from the house and water supply.

There should be in a septic tank system (a) a water-tight sewer leading from the house to the tank; (b) the sewage tank with one, or preferably two, chambers; (c) the tight outlet sewer, and (d) the distribution field.

The house sewer should be salt glazed sewer pipe, or other water-tight material; have a diameter of 5 or 6 inches, and a grade of 2 feet per hundred if possible; and a straight alignment. It should be placed 1 or 2 feet below the level of the basement floor, and below the frost line, with bells placed up-stream and cemented water tight.

The tank with two chambers, Fig. 154, should permit settlement and anaerobic decomposition in the first chamber, and aerobic decomposition in the second, which will be longer and shallower than the first, and separated from it by a baffle. An automatic cast-iron sewage siphon is provided to cause periodic discharge from the second compartment, providing capacity of 40 gallons per person per day, or 200 gallons

for an average farm. The siphon causes intermittent discharge, and a flood which extends through the absorption system. The outlet is above the sediment, and below any scum. The siphon entraps a column of air between two columns of water. When the water in the chamber rises to the chosen discharge point, the pressure forces the air out, upsets the balance, and causes a rush of water to the absorption sewer. An emergency overflow should be provided, to operate if siphon clogs. The tank may be constructed in a pit, using the soil for the outer concrete form. A reinforced concrete lid and opening should be provided for inspection, and for the annual removal of solid sediment. A tight sewer should lead to the absorption system, and connect with the laterals through V-shaped tile junctions laid level crosswise to allocate the flow evenly to the different lines.

Absorption Systems. — The absorption system consists of an underground drainage system made of ordinary farm tile-drains, in which the direction of flow is reversed. The absorption system is usually constructed of 4-inch clay tiles, laid with 1/4-inch joints, at a depth of 15 to 18 inches below the ground surface. The fall is about 2 inches for each hundred feet. The total capacity of the tiles should be about 75 per cent of that of the discharge tank from which the sewage comes. The tiles may be laid in parallel branches, 10 to 15 feet apart, leading from the main outlet pipe. Sewage is discharged from the sep-tic tank suddenly and in large quantities, so that the whole tile system will be filled at once. The sewage is then absorbed by the surrounding ground, and the soil bacteria destroy the harmful elements still present in the sewage. In case the soil is impervious or poorly drained, tile underdrains should be laid between 1 and 2 feet below the absorption tiling, so as to prevent water-logging of the soil. The trenches in which the absorption tiles and drain-tiles are laid may be filled with graded gravel, or the whole area may be underdrained and prepared as a sand-filter. The capacity of the absorption system can be increased by the cultivation of grasses or lawns on the absorption field. The discharge from this underdrainage system is

usually clear water, and can be turned, with safety, into any running stream. The absorption system in outline may resemble a 4-tined fork.

Sewage-Irrigation. — In arid and semi-arid or droughty regions, economy is often effected by using sewage in the irrigation of meadows, corn, and other agricultural crops. In such cases the sewage is collected in concrete storage basins or tanks, and by means of gate-valves distributed alternately on dry areas which are under cultivation. There is a close relation between irrigation and drainage; some soils require both for their highest development. Droughty soils are best adapted to sewage-irrigation.

Good results are being obtained from sewage disposal by irrigation use near Vineland, New Jersey. Vegetables that may be eaten raw should not be grown on land thus irrigated, as there is danger that disease germs may remain alive in the sewage.

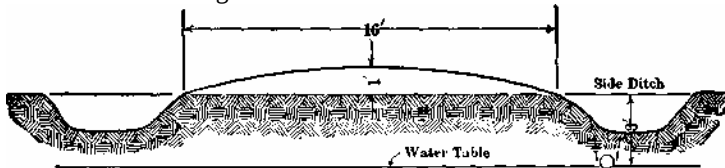


FIG. 155. Cross section of road showing location of tile drain.

Road Drainage. — There is no factor entering into the construction of good roads that is more important than drainage. It is the very foundation of good roads. With proper drainage almost any road will be a good road; without it, no road, no matter what the cost, can remain a good road very long. Road drainage divides itself into two classes, surface drainage and subsurface drainage. Surface drainage is the process of taking off the water that falls on the road from above or runs on to it from adjacent surfaces. Subsurface drainage is designed to carry away the water moving up into the roadway from below. After water has reached the tile-lines through the surface of the road, it has done all the damage of which it is capable;

the water should therefore be intercepted, both by sub-drainage from below and by surface drainage from above, before it reaches the road and saturates it, or from the gravel shoulder of the pavement to the ditch.

To prevent water from standing in puddles on the surface and to prevent its penetrating the road, it is necessary to crown the road and keep the surface smooth and free from holes. The split-log drag is useful in maintaining a smooth, impervious surface on earth roads. For any surface like gravel or macadam, $\frac{1}{2}$ to $\frac{3}{4}$ of an inch for each foot of the half width

of the road is sufficient crown; for an earth road 1 inch is sufficient. On hill roads, "water-breaks" or mounds will help direct water from wheel-trails. Properly constructed side-ditches are necessary to carry away promptly and completely water that has run off the road or collected from adjacent territory. Such side-ditches need not be deep, but they should be of such design or shape that they can be readily constructed and maintained with ordinary road machinery. No obstructions should exist between the center of the road and the side-ditch to prevent water from running directly from the road to the ditch.

The tiles should be laid not less than 3 or 4 feet below the crown of the road, and on a uniform grade-line. In case the road extends parallel with the direction of the flow of the groundwater, two lines of tiles, one on each side of the road, may be required. The waterway areas of all bridges and culverts should be ample, and the culverts should be constructed of durable material. Four-inch tiles with a fall of 0.3 foot to each 100 feet will usually be ample for underdrainage. The tiles should be placed on the higher side of the road and just inside the gutter. Water should be taken out of the ditches frequently, at least every 1000 feet in rolling countries. In very flat locations it is necessary to carry it a much greater distance. To prevent undermining there should be an outlet structure at the outlets of all culverts and drains.

Airport Drainage. — Landing fields should be firm and free from excess water at all times. The hard surfaced runways will require drains for intercepting surface water with capacity approaching that provided

for city pavements. In humid sections of the United States, drain pipe capacity for runways of the order $\frac{1}{2}$ inch to 1 inch an acre an hour should

be adequate. The ordinary airport field outside runways should be provided with at least first class field drainage capacity. Drain pipe of material that will meet standard tests may be placed in pervious backfilled trenches along both edges of the runway on a good working grade, with a minimum depth of 30 inches to the top of the pipe. A third tile-line will be required under the center of a graveled runway where it is on wet heavy land, and 150 feet or more in width. The backfill must be permeable and firm, and the use of crushed rock or gravel would insure this. Inlets should not be permitted on airports as they are dangerous. All surface water should be admitted to the drains through gravel or rock-filled trenches. It may also be advisable to backfill some of the subdrain trenches with gravel. Each airport drainage problem should be given careful individual study.

Anti-Malaria Drainage. — Drainage to eliminate breeding places of malaria-carrying mosquitoes is no different than thorough agricultural drainage. It is a permanent treatment and may be most economical in the long run. Underdrainage may be required to prevent slips and subsidences (13).

QUESTIONS

1. Describe the proper method of drainage for barnyards.
2. Where should tiles be placed to drain a foundation?
3. What points should be observed in designing tiling for orchards?
4. How is sewage rendered sanitary by a septic tank?
5. Describe the general construction of a septic tank.
6. How may liquid drainage be disposed of, after it leaves a septic tank?
7. What useful disposition may be made of drainage from a septic tank and under what conditions?
8. What methods can best be used to dispose of surface drainage on farm roads?
9. Where should tiling be placed in road drainage?
10. Describe the essentials of airport drainage.

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PART IV —DRAINAGE SURVEYING

CHAPTER XXIV

DRAINAGE SURVEYING AND PRACTICE

The planning of drainage systems requires precision. A careful survey should always precede the construction work, in order that the completed system may be effective. The drains must be properly arranged, and the number of branch drains worked out with care and mathematical exactness.



FIG 156. Class starting a survey for drainage.

If the drainage system is simple, the plan may be easily made, and in some instances measuring instruments will be unnecessary. Usually, however, the system will be so large or so expensive, or the grade will be so flat, that a careful survey and the assistance of a competent drainage engineer will be needed. A good drainage specialist should possess a practical knowledge of the local rainfall, ability to estimate the amount

of flood-water, knowledge of the subsoil and general character of crops suited to the land, and experience in calculating the proper sizes of open ditches, as well as tile-drains. He should also be able to make the field survey with rapidity and accuracy, to record it properly and to interpret it. In addition he should have the tact, personality and control of temper which are necessary in dealing with men. He must be a man of integrity,



FIG. 157. Making a survey for tile drainage.

resolute, yet discreet, of sound judgment, and proof against bias of any kind.

Instruments. — In laying out drainage systems, three surveying instruments, the chain or tape, the rod and the level are necessary. In surveying, horizontal distances are measured with a surveyor's chain or tape, with stadia or with a speedometer.¹ Accessory instruments are range poles and plumb-bobs. Estimates of horizontal distances may be made by pacing, and for counting steps over a long course a pedometer may be found helpful. A young surveyor should learn the average

¹ Certain instruments are equipped with two additional horizontal hairs by means of which horizontal distances may be determined. When the rod is seen at a distance through the instrument, the space between the two hairs as seen on the rod, when multiplied by a constant (usually 100), gives the distance.

length of his normal and also of his assumed or pacing step, by pacing and walking over a measured 300-foot level course. The farmer should be more or less familiar with engineering technique, so that he may appreciate the work of the engineer, and be better qualified to understand when and where the services of the latter are really needed.

Chains. — There are two kinds of chains in common use, the surveyor's or Gunter's chain, and the engineer's chain. The Gunter's chain is 66 feet long, divided into 100 links of 7.92 inches each. One Gunter's chain equals 4 rods. One mile equals 80 chains, 1 acre equals 10 square chains. On account of its simple relation to the mile and the acre, the Gunter's chain is especially adapted to land surveys. The engineer's chain is either 50 or 100 feet long, and is



FIG. 158. Surveying instruments used in drainage work.

divided into links of 1 foot each. Chains have been largely superseded by tapes. The chief advantage in the use of the chain is that it is not easily broken. The disadvantages are as follows: (1) a chain stretches or increases in length on wearing; (2) it is heavy and awkward for field use; (3) the links become distorted with rough usage, and this distortion changes the length of the chain; (4) the links may double back or kink, thus causing error; (5) it is not closely graduated to hundredths of a foot, as are some tapes.

There are three kinds of tapes in common use, the cloth, the

metallic and the steel. Cloth tapes are of little service, for they stretch with usage.

Metallic Tape. — The so-called metallic tape is made of fabric, with fine wires woven lengthwise in the material, to prevent stretching. Such tapes are made in lengths of 25, 50 and 100 feet, and are graduated into feet, tenths, and half-tenths of a foot. They are convenient to use because they are of light weight and are easily read. The disadvantages in their use are two: they stretch to a certain extent when pulled,

and they wear out very quickly.

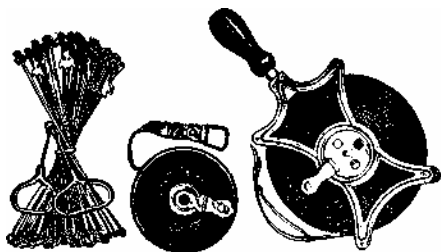


FIG. 159. Left, surveyor's chain; center, metallic tape; right, steel tape on reel.

Steel Ribbon Tapes. — Ribbon tapes may be obtained in various lengths up to 500 feet. The most common lengths are 50 and 100 feet. The shorter tapes are graduated into feet, tenths, and hundredths throughout their entire length; but the longer ones are graduated into feet only, the 5-foot marks being numbered, and each end foot being graduated into

tenths for convenience. The advantages in the use of the steel ribbon tape are as follows: (1) a steel tape stretches very little with use; (2) it is light and easily handled in the field; (3) it does not become distorted without breakage; (4) it gives smaller subdivisions and thus may be more accurately read.

The disadvantages of a steel tape are that it breaks when it kinks, and that the marks may be hard to see.

Errors in Using the Tape or Chain — Errors in the use of the steel tape are of two kinds, cumulative or compensating. A cumulative error is one that grows or increases with each application of the tape. A cumulative error may be due to imperfect vertical or horizontal alignment of the tape, or to incorrect length of tape.

A compensating error is one which grows alternately larger

or smaller with successive applications of the tape, and may be due to the degree of tautness, the setting of the pin, or the swinging of the plumb-bob when chaining on steep slopes. To avoid errors, when starting to use a steel tape, it is important to find the zero point, and to place pins carefully at proper marks on the tape. The tape must be on line and held in a horizontal position, using a plumb-bob on sloping ground. Both chain-men should count the pins used. Avoid too much sag by subjecting the tape regularly to a pull of 15 pounds. Fractions must be carefully estimated, using the smallest graduations, usually one end of the chain.

Method of Chaining. — A horizontal line is measured by two chainmen, using a chain or tape and a set of eleven steel marking pins. One man, called the head chainman, carries ten of the marking pins and the front end of the chain, while the rear chainman takes the eleventh pin and the rear end of the chain. The head chainman goes forward, keeping as nearly on line as possible. The rear chainman, starting over his point, places the head chainman in line with some object, such as a sighting rod which marks the other end of the line. The rear chainman holds his end of the tape at one side of the initial point or pin, so that it will not be disturbed before the forward pin has been set. When the head chainman is nearly in line, he holds a pin upright on the ground a foot or so from the end of the chain, and the rear chainman motions him to the right or left until his pin is on line. When the head chainman has the pin in line, he takes the precaution to see that there are no kinks and then stretches the chain tight and makes sure that there are no obstructions to cause bends in the chain. At the same time, the rear chainman holds his end of the chain on the pin and calls out, " Stick." The head chainman then places his pin at the end of the chain and calls back to the rear chainman, " Stuck." The rear chainman then pulls the pin at his end of the tape and keeps it as a record of the number of chain-lengths measured.

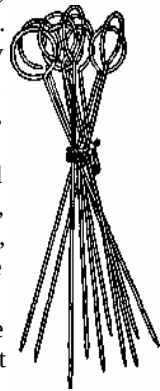


FIG. 160.
Surveyor's pins,
or arrows.

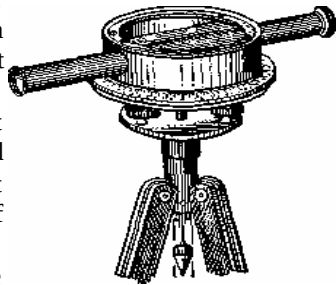
The chainmen then proceed one chain-length to the next pin. Just before reaching the next pin, the rear chainman calls out, "Chain," to give the head chainman warning that he has nearly reached the chain-length. The process of measuring chain-lengths is then repeated. When ten chains have been measured, the head chainman will be out of pins. He then calls to the rear chainman who brings forward the ten pins, the eleventh still remaining in the ground to mark the new starting point. The pins should then be counted by both chainmen. Every time ten chains are measured, a record is made in notebooks, which should be kept by both men, and the process repeated until the entire line is measured. Where the ground is so steep that a full chain-length cannot be used, care must be exercised that no errors are made. In such cases, fractional chain-lengths are used, and the operation is called "breaking chain."

The Level and Level Rod. — The instruments most useful to the farmer, as well as to the engineer, in laying out drains, are the level and rod. The use of these instruments is very simple and the theory can be mastered by any intelligent man in a short time. Skill in using them will come with practice. Leveling is a process by which heights or elevations of definite points on a line or area, above an arbitrarily adopted plane, are determined. This arbitrary plane is called a "datum plane," and is chosen so that it always lies below the lowest point which is to be determined. Thus, a point of 100-foot elevation is actually 100 feet above this imaginary datum plane. If the elevation of all points above the datum plane is determined, the datum plane itself being constant, the elevation of one point with reference to another is easily determined by the subtraction of their respective elevations.

The engineer's level consists of a telescope forming the line of sight, attached to a bubble-vial and a vertical axis or spindle. There are two types of engineer's levels, the dumpy level and the wye-level. In the former the telescope is fixed to the support, while in the latter the telescope rests in a Y-shaped support, from which it can be easily and quickly removed. In the

wye-level, the bubble-tube is attached to the telescope barrel on the under side. The telescope is attached to standards on Y's, which in turn are attached to the level on a vertical spindle, or axle, about which the whole instrument may be revolved. The whole is attached to a tripod head to which are also attached three wooden legs, similar to, but heavier than, those on a photographer's tripod. The important parts of the level are the eyepiece, the object-glass, the focusing screw, the bubble-vial, the adjusting screws, and the vertical action or spindle. Some types of levels are equipped with a magnetic needle and graduated circle to facilitate the measurement of angles and to determine the bearing of lines.

Use of the Level. — As the level-man looks through the telescope, there appear at a distance two black lines, one horizontal and the other vertical, crossing each other at the center of the telescope. These are called cross hairs. When the telescope is level, that is, when the level-bubble is in the center of the level-tube, the following facts are to be noted: (1) The line from the levelman's eye at the eyepiece of the telescope, and to the



intersection of the cross hairs, is a level line and is parallel to the datum plane. (2) The height of this line above the datum plane is called the "height of instrument." (3) Every point of this line, produced forward or backward, is at the same height or elevation as is the instrument.

Cheaper Levels. — There are a number of cheaper levels that will serve, where there is a fair amount of fall to the drainage area. These are variously designated as drainage levels, grade-levels, explorers' levels, and architects' levels. They operate on exactly the same principle as the instruments already de-scribed, differing from them principally in the grade of workmanship and material used in manufacture.

Where tiles of good size are to be laid with a fair fall, rather crude devices, costing only a few dollars, are sometimes used for leveling with satisfactory results. Some of these simple devices will be briefly described. The carpenter's square and plumb-line level-device is made by fastening the ordinary carpenter's square on top of the stake with a plumb-line attached at the angle of the square. When the vertical leg is parallel to the plumb-line, the horizontal leg of the square is a level line and may be used as a line of sight in producing this level line for purposes of establishing grades.

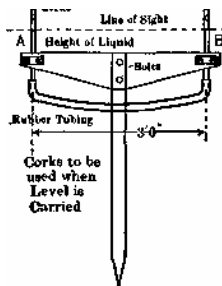
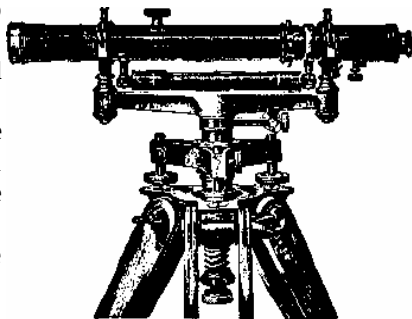


FIG. 162. Water or hose level (after Davidson). T.

The water-level consists of two vertical glass tubes attached at both ends of a T-shaped stand and connected by a few inches of rubber tubing. The stem of the T should be as nearly level as possible. Colored water in the tubes will rise to the same level in each tube, and a line connecting the surfaces of the colored water in the tubes will be a level line.



There are numerous other types of home-made levels, such as the plumb-bob and "A," carpenter's level, straightedge, etc.;

but their accuracy is no greater than that of the devices already described, and they are not so convenient to operate.

The Hose Level. — Mr. J. O. Jeffrey in his text on land drainage describes a form of home-made device for running levels, which, if handled carefully, is an excellent and accurate leveling instrument. It consists of a long hose with glass tubes connected on both ends, and depends on the simple principle that water seeks its own level. The hose is usually $\frac{1}{2}$ inch garden hose 60 feet long, and the glass tube may be made from ordinary steam-boiler water-glasses. The hose is filled with water, care being taken that no air-bubbles are entrapped; the water is then held within the hose by the levelmen, who keep their thumbs over the glass tubes while proceeding from one station to the next. The rods are made by nailing yardsticks to a narrow piece of board about 7 feet long.

Level Rods. — Level rods are classified according to their construction as either self-reading or target rods, or they may be combinations of the two. Self-reading rods are those which can be read directly from the instrument by the levelman, while the target rods can be read only by the rodman. For drainage work, self-reading rods are preferable. The rod most used by engineers is the Philadelphia rod, which can be used either as a target rod or as a self-reading rod. It is graduated to feet, tenths and hundredths of a foot, graduations being plainly painted on the face of the rod. A target is provided, having a vernier for precise readings, but it is not necessary to use it. The rod is made of two strips of wood, ordinarily $6\frac{1}{2}$ feet long, one of which slides in the groove of the other. The target is free to move along the lower $6\frac{1}{2}$ feet of the rod, or it may be clamped in any position. A clamp is also provided for holding

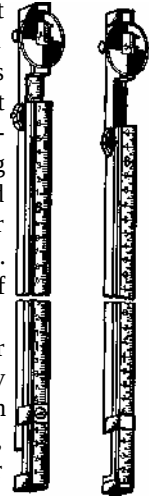
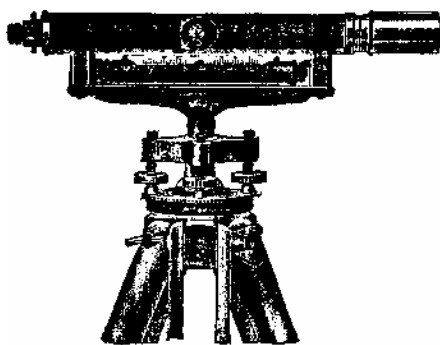


FIG. 164.

Leveling rods; the one to the right is a non-speaking rod, known as the New York, and the one to the left is a speaking rod, known as the Philadelphia.

the two parts of the rod in any position desired. When the rod is fully extended, the graduations on the front faces of the two parts are continuous and the readings can be made directly by the levelman himself. When used as a target rod for reading above $6\frac{1}{2}$ feet, the target is clamped at the $6\frac{1}{2}$ - foot graduation, and the readings are made from the scale on the back of the rod.

The Flexible Rod. — This type of rod is a long strip of fabric, having the graduations painted in feet, tenths and hundredths



of a foot as with the Philadelphia rod. It may be rolled up and carried in the pocket. When in use it is fastened with thumb tacks to a piece of pine board $\frac{3}{4}$ inch by 4 inches by 14 feet. When the leveling is finished the board may be discarded.

Preliminaries. — Before the use of the level is explained, some descriptions and definitions will be given.

A *level surface* is perpendicular to a plumb line at any point on the earth's surface.

Differential leveling consists in finding the difference of elevation between two or more points.

Profile leveling consists in finding the relative elevations of a series of representative points along a surveyed line, for the purpose of constructing a profile or vertical section. A fine thread and pins are useful in adjusting the grade lines.

A *contour line* is a line all points of which are at the same elevation. *Contour leveling* is an application of the methods of profile leveling to the location of contour lines. Contour lines may be found either by locating points of equal elevation, or by taking elevations at regular intervals and interpolating the contours from plotted data.

Cross-sectioning consists of staking out the limits of a transverse section of a ditch or levee, and usually includes an estimate of yardage.

Definitions. — A *datum plane* is a plane to which the elevation of each of the observed points is referred. It may be sea-level or an imaginary or assumed plane. *Bench Marks* (B. M.) are permanent objects, the elevations of which are determined or assumed, and recorded for future reference. Bench marks are taken at the terminals of the line and intermediate benches may also be used. *Turning Points* (T. P.) are intervening points upon which the level rod is held, for the purpose of determining the height of instrument (H. I.). *Stations* (Sta.) are points upon which the level rod is held. They are usually 100 feet apart. *Backsights* (B. S.) are readings on points of known elevation. *Foresights* (F. S.) are readings taken on points for the purpose of obtaining their elevations.

Backsights are taken for the purpose of obtaining a new height of instrument; they are plus quantities and are added to the elevation of the point sighted at. Foresights are minus quantities and are subtracted from the height of instrument to get the elevations of points.

Height of Instrument (H. I.) refers to the sight-line or plane in which the telescope revolves, and from which the levelman makes his readings. *Elevation* (Elev.) is the vertical height of a point as compared with some reference point or datum plane.

Grade. — A grade-line is a line along which the water in the drain is to flow. In any particular drain, there may be a uniform grade throughout or different grades. The tile-base is fixed at an arbitrary depth at the outlet or head, and at other control points along the lines; and the fall between control points is prorated among the intervening stations.

Cut. — The cut, or depth of the excavation, is the difference between the ground elevation and the grade-line at each station. It is determined by subtracting the grade elevation of the point from the surface elevation of the same point.

Setting Up the Level. — Secure a firm set-up, and if the ground is sloping place two legs of the tripod downhill. After

bringing the head of the tripod as nearly level as possible by changing the tripod legs, place the bubble parallel to an opposite pair of leveling screws and bring the bubble to the center, remembering that both thumbs turn out or both in, and that the bubble will go in the direction in which the left thumb moves. When the bubble is in the center, turn through 90 degrees and level over the other set in a similar manner. Care should be taken that the leveling screws do not bind, but they should be brought snug against the plate.

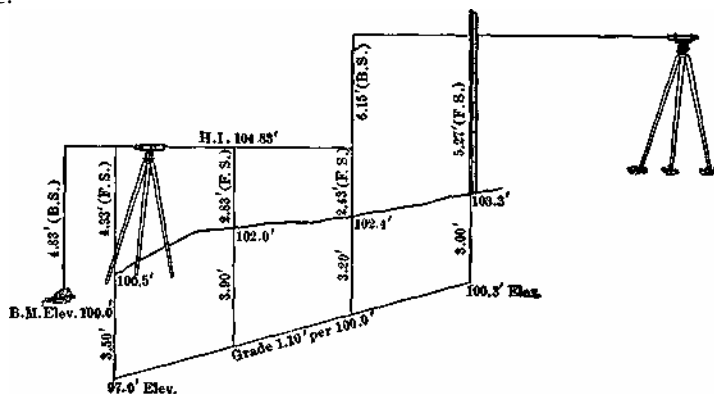


FIG 166 Diagram showing method of using level.

Ordinarily before taking any sights, the cross hairs are brought into the most distinct position possible by moving the eyepiece barrel. The telescope is then focused on a point; the eye is moved slowly behind the eyepiece, and if there is an apparent quivering of the cross hairs on the object, it signifies either that they are not in the most distinct position possible or that the object-glass is not clearly focused, or both.

The *adjustment* of the level consists in bringing the various parts of the instrument into proper relation to each other. Certain tests may be made, and the level may be adjusted if necessary. An outline of the different adjustments will be given later.

The sketch will explain the work of differential leveling. In

profile leveling, several foresights, called intermediate sights, may be taken at each set-up of the level.

Form for Field Notes. — A field book may be divided into six columns on the left-hand page and three or more on the right, page 318.

Proof — The sum of the backsights minus the sum of the foresights on turning points should equal the difference in elevation of the first and last stations in the series. It is recommended that a return be made to the first bench mark.

How to Check Readings — The extra man in the squad, if there be one, should go with the rodman, so as to get an extra check on the target-readings. He may act as note-keeper.

CARE OF FIELD EQUIPMENT

In going through a narrow passageway, always carry the instrument in front of you. In going over a fence, place the level on the other side, setting the legs of the tripod well apart so that it will stand. In windy weather, set the instrument firmly on its legs so that it will not blow over. When shouldering the instrument, always tighten the clamp -screws slightly on the spindle. With the level, clamp the telescope so that it hangs down. Great care should be used in passing through timber with low branches.

Setting Up Indoors — In setting up an instrument indoors, press the shoes firmly into the floor, putting each point into a crack, to insure against spreading of the tripod legs. It is convenient to have a triangular frame of narrow strips of wood into which the tripod legs may be set. If the level is to remain for any length of time outside the rack, it will be best to unscrew the upper part from the tripod and place it in a safe position.

The Sun-Shade — The sun-shade is a part of the telescope-tube, and should always be attached thereto, regardless of the weather, as the adjustments of a delicate instrument may be affected by a change of weight in its axis. In attaching or re-moving the sun-shade or the dust-cap, always hold the telescope

SURVEY FOR DRAINS FOR DAIRY BARN May 2, 1919

(LEFT-HAND PAGE)						(RIGHT-HAND PAGE)		
Sta.	B. S.	H. I.	F. S.	I. S.	Elev.	Grade Elev.	Cut	Remarks
B. M.	4.83	104.83			100.00			Top of Fire Hydrant by Barn
0				4.33	100.50	97.00	3.50	
1				2.83	102.00	98.10	3.90	Fall 1.1' per 100'
2				2.43	102.40	99.20	3.20	
T. P.	1.34	102.78	3.39		101.44			
B. M.	6.17		5.27		97.51			Nail in root of tree near 2 + 30
			8.66		100.00			
			6.17		97.51			
			2.49	←check→	2.49			

firmly with one hand and twist the shade or cap to the right with the other to avoid unscrewing the object-glass.

Setting Up in the Field. — When the instrument is set up in the field, the legs of the tripod should be brought to a firm bearing, with the tripod head approximately level. Give the tripod legs additional spread in windy weather and in places where the instrument may be subjected to vibration or other disturbance. On side-hill work, always place two legs downhill. It is much easier to keep the instrument level if two tripod legs, as well as an opposite pair of leveling screws, are placed in the general direction of the line of levels.

Exposure of the Instrument. — Never attempt to use a level in a rain storm. In threatening weather it is a good plan to carry a waterproof bag, and cover the instrument with it in case of rain. Excessive dampness fogs the lenses so that it is impossible to work. Never put a wet instrument into the case, but wipe it thoroughly dry before returning it; otherwise the lenses may become fogged so that it will be impossible to use them when the instrument is taken out of the case. The instrument should be protected from dust and dirt and should not be subjected to sudden changes of temperature. When an instrument is brought from a cold to a warm temperature, it should be covered with a bag or cloth to protect it from condensing moisture. Never leave an instrument unguarded or exposed, in such places as pastures, or drive-ways, or where blasting is in progress. Never leave an instrument standing in a room on a tripod over night.

Manipulation of Instrument. — Engineering instruments are delicate, and the operator should cultivate the habit of delicate manipulation, from the beginning. The parts of these instruments, when once injured, can never be restored to their original perfect condition. Carelessness in the use of field instruments is indicative of lack of skill and experience. When any screw or part of the instrument works with difficulty immediate attention should be given to it, and repairs made if necessary. Delay in making repairs often permanently injures the instrument.

Foot Screws. — If the screws used in leveling the instrument are too loose, it will rock on the tripod, and accurate work cannot be done. If the screws are too tight the instrument will be strained and damaged and the observations will be less exact. In leveling an instrument, therefore, the foot screws should be dropped just to a snug bearing; but needless turning and wear of the foot screws may be avoided if the plates are brought about level when the instrument is set up. This may be accomplished by shifting the legs upon the ground. In leveling, an opposite pair of foot screws should be shifted in the general direction of the line of foresight before leveling up.

Clamps. — The ears of all clamp-screws on engineering instruments are purposely made small to prevent abuse. Do not overstrain the clamps. Find out, by experiment, just how tight to clamp the instrument in order to prevent this, and then act accordingly. Never touch the capstan-headed adjusting screws on an instrument, unless you are positive that it is necessary and that you have the authority.

Lenses. — The lenses of a telescope should never be removed or rubbed, as this will mar the finish which is given to their surface, in the final stage of manufacture, by the bare human hand. Should it be absolutely necessary to clean the lens, do so cautiously, using a very soft rag, and taking care to avoid scratching or marring the polished surface. A little alcohol on a rag will be helpful in removing grease. Protect the lenses from flying sand and dust, which will in time obscure the image in the lens.

Tripod Cleaning — Clean the tripod shoes before bringing the instrument indoors. Leave the tripod standing on its three legs.

Leveling Rods and Flagpoles — Leveling rods, stadia rods and flagpoles should never be left leaning, or placed where they may fall. Avoid injury to the clamps, targets and graduations, and do not mark the graduations with a pencil. Needless exposure of rods to moisture or sun will injure them materially. In carrying a rod, let the ungraduated edge rest on the shoulder.

Chains and Tapes. — Chains and tapes are liable to break, especially in cold weather. They should be handled carefully and not jerked. On driveways, streets, etc., especial care should be taken to protect the tape. Ribbon tapes should be done up in 5-foot lengths in figure-eight form, unless reels are provided. The figure-eight may then be thrown into a circle. Such tapes should be wiped clean and dry at the end of each day's work. Great care should be used in cleaning, when using a tape near salt water. Tapes may be oiled lightly before storage for a long period of time.

Tape Repair. — Care should be taken in unwinding and using steel tape, to avoid getting any kinks in it, otherwise a jerk or pull will cause a break. Avoid permitting heavy vehicles to run over the tape.

In case of breakage, a little steel sleeve may be soldered over the break, or preferably a type of repair sleeve (carried by dealers in surveying instruments) may be used which is clamped to the broken ends by means of screws.

In folding up a surveyor's chain, begin at the center and fold the chain two links at a time.

The Planetable. — The planetable is an instrument by means of which points are located in the field directly on the map, by graphical methods. The map is placed on a drafting board which is fastened to a tripod. The board may be revolved about a vertical axis. Traverse lines and points to be mapped are plotted by means of a ruler or straightedge to which a line of sight is attached. This line of sight is usually a telescope with cross hairs, the whole, with straightedge, being called an alidade. From a mathematical standpoint the planetable is not an accurate instrument, but from a practical standpoint it is most useful and sufficiently accurate to compete with the ordinary office methods of plotting. All errors become inappreciable when reduced to the ordinary scale of maps.

Mapping directly by use of a planetable has the advantage of dispensing entirely with field notebooks and saving the trouble of plotting from field notes. Planetables are of several kinds and sizes; but the one most useful in drainage work is the traverse

planetable, which consists of a board about 15 inches square, mounted on a light tripod and having a small compass needle, or declinator, set in one edge of the board and flush with its top. The directions of the lines on the map are determined by an instrument called an alidade, which consists of a ruler or straightedge, with two vertical sights, like those on a surveyor's compass, mounted on both ends of the ruler.

In tracing out a drainage line the instrument is set up at alternate stations only, the unoccupied stations consisting of

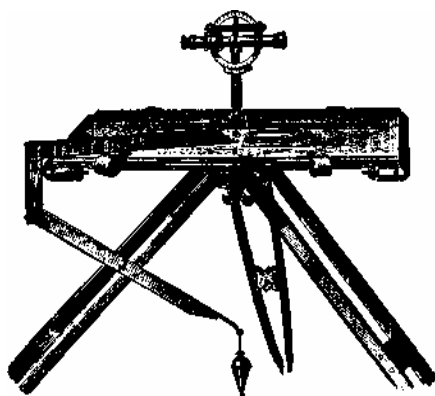


FIG. 167. A planetable.

natural objects occurring along the line of traverse, such as trees, stumps, roads, fence-posts, etc.

In sketching contours, an alidade equipped with telescope and stadia hairs is desirable. A skilled operator can get approximate elevations and contours with a traverse-table and ruler. In very accurate planetable work, the planetable is set up at every station, and the map is oriented by putting the fiducial edge of the alidade on the last foresight and turning the table until the line of sight points to the last station

occupied. In traversing, where every alternate station only is occupied, the orientation is checked by means of the declinator or magnetic needle.

ADJUSTMENT OF THE WYE-LEVEL

Adjustment I

To Make the Line of Sight Coincide with the Axis of the Telescope-Tube.

Set the level up firmly, with one pair of diagonally opposite leveling screws in line with a distant object to be sighted at.

Focus the telescope upon the object, clamp the horizontal motion, and, by means of the leveling screws, make the horizontal cross hair hit a definite point, such as a pin or nailhead. Rotate the telescope-tube through 180 degrees in the wyes, and see if the cross hair still falls upon the distant point. If so, the adjustment is correct; if not, mark the second sight and bring the cross hair halfway back to the first point by means of the capstan-headed screws at the side of the telescope. Bring it the rest of the way back by means of the leveling screws. Make a similar test for the vertical cross hair and, if in error, correct by the capstan-headed screws at top and bottom of the telescope.

Check: Again rotate the telescope 180 degrees in the wyes, and see if the intersection of the two cross hairs still falls upon a fixed point. If not, repeat the process until it does.

The line of sight is then coincident with the axis of the telescope-tube, and, assuming that the rings are of the same size, it is parallel to the axis of the wyes.

Adjustment II

To Make the Bubble-Tube Parallel to the Axis of the Wyes and Hence to the Line of Sight.

With the level firmly set up, center the bubble first over one pair of leveling screws, and then over the other. Center it more carefully over the first pair, and clamp the horizontal motion. Remove the telescope from the wyes, turn it end for end and replace it. If the bubble is still centered the adjustment is correct; if not, bring the bubble halfway back to center by means of the adjusting screws at one end of the bubble-tube. Then center the bubble by means of the leveling screws.

Check: Again change the telescope-tube end for end in the wyes, and see if the bubble remains centered.

Adjustment III

To Make the Bubble-Tube Perpendicular to Axis of Revolution.

After adjustment II has been completed, the telescope-tube is replaced in the wyes in its original position, and the bubble

is carefully centered. The horizontal clamp is loosened, and the level is revolved 180 degrees about the axis of revolution. The bubble should still be in the center; if it is not, bring it halfway to the center by means of the large Y nuts at one of the wye posts. Bring the bubble the rest of the way back by means of the leveling screws.

Check: Again revolve 180 degrees about the axis of revolution and see if the bubble remains centered.

ADJUSTMENTS OF THE DUMPY LEVEL

The Horizontal Cross-hair — Level the instrument and sight the horizontal cross hair at some well-defined point. Revolve the telescope slightly about the vertical axis by means of the leveling screws. If the point appears to move off the hair, rotate the cross hair ring until the point appears to remain on the line.

The Bubble Adjustment — To make the bubble-tube perpendicular to the vertical axis of the instrument. The construction of the dumpy level makes it necessary to complete this adjustment before making the line of sight parallel to the bubble-tube. Center the bubble over one pair of foot screws, turn the instrument 180 degrees about the vertical axis. Move the bubble *halfway* back to the center by means of the capstan-headed adjusting screws at one end of the bubble-tube. Repeat for a check.

The "Peg" Adjustment — To make the line of sight parallel to the bubble axis. Drive two pegs on slightly sloping ground 200 feet or more apart; mark them A and B. Set the level midway between the two stakes, in which case the error of the instrument will be equal at each station and the true difference in elevation will be determined. Find the difference in elevation by taking the difference of rod readings on the two pegs. Next set up near peg A, and take a rod reading on this point; with the difference of elevation already found by having set up between the two stakes, find the proper rod reading on the point B. Take a rod reading on B, and if this reading is in

error, bring the horizontal cross hair to the calculated reading by means of the capstan screws on cross hair rings. Check by repeating the readings on both points, having the bubble in the center for both sights.

The "peg" adjustment may be used for checking the combined first and second adjustments of the wye-level, which it may replace.

Maps and Records of Drainage. — It is important to keep records of the location and depth of tile-lines. When drained land is sold, a map showing the location of any tile-lines should accompany the deed. This enables the owner to make any needed extensions or repairs.

In mapping, drawings should be centered in rectangular areas. Proper scale, titles, and legends should be used, and all notations neatly lettered in so as to form a balanced map. A map may be laid out with rectangular areas by drawing horizontal lines with T-square, and perpendicular lines with triangle resting on the T-square. Regular symbols have been developed for representing streams, drains, roads, and other objects; and the student should learn to read and to make maps with neatness and facility.

Contour lines are lines passing through points of equal elevation, such as shore lines at different stages of water. A contour map shows the "lay of the land." A field may be surveyed for preparation of a contour map by staking out two rows of stations along each of two sides of the area at right angles and marking them with laths so that lines can be projected across the area and elevations obtained every hundred feet. Bearings may be made at each station and the water-table elevation obtained by difference so water-table contours may be plotted.

A *contour* or *topographic* map is a representation of the "lay of the land." First select the scale to be used, then draw boundaries and rule off inside these to represent 100-foot squares. The intersections will be numbered to correspond with the stations established in the field. Using the intersection for the decimal point, pencil in the elevation at each station. Choose a suitable contour interval and trace in these lines of equal elevation

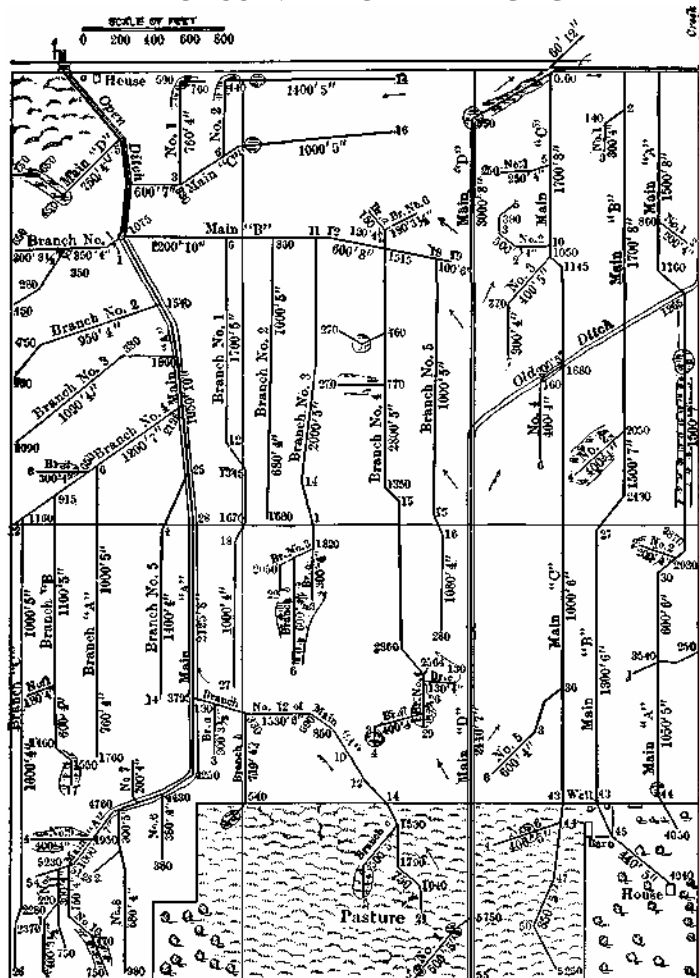


FIG. 168. A drainage map for 480 acres. From Farmers' Bulletin 187, U. S. Department of Agriculture.

beginning with the 100-foot level. After inking these contours and other permanent records, the 100-foot construction lines may be erased.

The *contour interval* is the vertical distance between contour lines on a contour map. A topographic map is useful in the design of drains, to secure proper grades. The steepest slope is always at right angles to the contours.

A *profile map* represents a section in relief. In case of a tile-drain, it represents the surface and grade-line, as though cut and exposed to view from the side. Sectionized paper is useful in plotting profiles. In making a profile map, choose a horizontal line to represent a base elevation like 100, and also a suitable *vertical scale* for elevations, and a *horizontal scale* for stations. Next plot the hub elevation at each station, and connect them to show the position of the stations. With a straightedge, or thread and pins, a grade-line can be tested and established at suitable depth economically. The depth to dig and height of grade-line at each station can be represented thereon. Studies of water-table and subsoil conditions can be similarly plotted on the profile.

The *drainage map* may be made by drawing all tile-lines to scale on a contour map of the area, and a planetable is helpful in mapping tile-lines in this way in the field. The location, length, and size should be indicated for each tile-line. The fall per hundred feet may be indicated if space permits.

Land Surveying — The *acre* is the unit of land measure in English-speaking countries. It contains 160 square rods; 4840 square yards, or 43,560 square feet. The *hectare* is the land unit in continental Europe, and contains 2.47 acres, or 10,000 square meters. Prior to 1784 areas of land were de-scribed by "metes and bounds," or by a written description of its measurements and boundary points. The U. S. System of Surveying the public lands was then established by Act of Congress. It provided a rectangular system controlled by *principal meridians*, and then a guide meridian each 24 miles conforming to the true meridian. At right angles thereto, standard parallels or *base-lines* are established, corresponding to parallels of latitude. *Range* lines are then run due north from the three intermediate *township corners*.

Townships are numbered from standard parallels north or

south, and from the meridians by ranges east or west. The townships thus formed contain 36 square miles or *sections* of 640 acres each. The corners of interior sections are then located. On account of convergence of the meridians the sixth interval will be fractional; at 40 degrees of latitude will measure only 79.92 chains, and is run straight from the fifth section corner to the one at the north line of a township, to avoid a jog. The north line of the fourth township is always a *correction line*, or next standard parallel. Fractional sections therefore are found next to the 24-mile guide meridian on the west, and next to the 24-mile correction line on the north.

Sections number across to the left from the upper right corner of the township, and back to the right through the second tier from the north, and so on.

Monuments are placed at section corners, and also each half mile on the section line. The latter are called *quarter corners*. These quarter sections are further quartered into *forties*. The monuments are of different durable materials, and should be carefully preserved. Abbreviations are used in marking monuments.

Blue-Printing — Maps made with India ink on tracing cloth or thin coordinate paper may be reproduced by blue-printing. The drawing is placed in the print-frame with the ink next to the glass. The blue-printing paper is placed back of this, the sensitized or colored side being toward the glass. Expose to the light for such a length of time as tests show to be necessary. Then rinse promptly in a bath before hanging up to dry.

QUESTIONS

1. Define: surveying, compensating error, cumulative error.
2. Describe: engineer's chain, Gunter's chain, metallic tape.
3. State the advantages and disadvantages of chains, metallic tapes and steel ribbons.
4. What is meant by "chaining"?
5. What is meant by "breaking chain"?
6. What is meant by "tallying"?
7. Describe two methods of measuring an angle with a tape.
8. Explain the principle of the vernier scale.

9. Define, "declination," "magnetic bearing," "true bearing."
10. Describe the present method of land subdivision.
11. Define: "legend," "scale," "profile."
12. Define "level lines."
13. What is a "speaking rod"?
14. Define: "height of instrument," "backsight," "foresight," "bench mark."
15. Upon what principle does direct leveling depend?
16. Name the leveling instruments.
17. Name the parts of the level.
18. Define "grade," "gradient," "proof."
19. Describe three adjustments of the wye-level.
20. Why is it hard to carry a line of levels over a hill?
21. State the ultimate object sought in adjusting a level.
22. Why is it best to set up a level midway between two points upon which readings are to be taken?
23. Define, "contour map," "contour line," "contour interval."
24. Describe two methods of tracing a contour line in the field.
25. Define "principal meridian," "guide meridian," "standard parallel," "range-line," "correction-line," "base-line."
26. Two sides of a field are parallel and measure 50 and 65 rods respectively. They are perpendicular to one end, which is 40 rods long. What is the area in acres?
27. How many rods of tile are required to tile a 40 with lines parallel, four rods apart and at right angles to one side? How could they be so located? If placed diagonally how many tiles would be needed?

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APPENDIX

FARM DRAINAGE LABORATORY EXERCISES

Numerous preliminary exercises should be undertaken and performed successfully before practical drainage construction is attempted. The following problems are given with the intention of familiarizing the student with the use of the level and other field tools necessary for successful work.

I. Chaining Practice.

- (1) Learn to handle the chain or tape and the pins. Estimate, pace, and then chain a line over a hill between two points not visible from each other. Repeat this, each man acting as "lead man " or as " captain," then check results.
- (2) To set a stake in a line perpendicular to a given line at a given point, the stake being over 150 feet from the given line.
- (3) To find where a perpendicular from a given point without a line will meet that line, the given point being over 300 feet from the given line.
- (4) To establish a second point that shall make, with a given point, a line parallel to a given line. The parallel lines are to be over 140 feet apart.
- (5) To measure the distance between two points inaccessible from each other.

II. Leveling Practice.

- (1) Define: datum plane, bench mark, stations, backsight, height of instrument, foresight, elevation.
- (2) Find the difference in elevation of two points and the bench mark, stations being at least 200 feet apart, (a) when the difference can be found by one setting of the

instrument, (6) when the difference cannot be found by one setting of the instrument.

- (3) Find the difference in elevation of six stations and the bench mark. Stations 100 feet apart, (a) when all the readings can be taken by one setting of the instrument, (b) when no more than two readings can be taken from one setting of the instrument. Sketch a profile of (3) on profile or coordinate paper. Show elevation, cut, and gauge height at each station.

- (4) Find difference in elevation of two points not less than half a mile apart, and re-check.

III. Examination of a tile system in the field. Examine and make sketches.

IV. A study of the effect of tile-lines on the water-table. Note soil strata, elevations and plot profile. (Plate I-a.).

V. Study soil, subsoil, and water-table on a low area needing drainage. Sixty to one hundred stations. Prepare soil and water-table profile map on two lines of boring. (Plate I-b.)

VI. Prepare a contour map of fifty to sixty stations, showing surface of soil and water-table. (Plate II.)

VII. Methods of staking out a drain system after having decided on a location. Name of lines run. Setting of stakes.



FIG. 169. Measuring runoff with current meter.

- Distance between stations, etc. Find the elevations of all stations.
- VIII. Measurement of runoff by use of floats, and by use of the Cipoletti weir method.
- IX. Find the grade-line of the tile-lines under the soil and figure the fall per hundred feet; find the cut at each station; and figure and make typewritten estimate on the cost of the system. Prepare profile map of main drain and the longest lateral, on coordinate tracing paper, showing "cut" and "gauge height" at each station. (Plate III.)
- X. Make record of drainage system on a contour map by means of planetable.
- XL Practice in setting grade-laths.
- XII. Each student will be given practice in preparing trench and laying tile.
- XIII. With a hammer and chisel, cut a hole in an 8-inch tile large enough to receive a 3-inch tile.
- XIV. Determination of soil-moisture and soil-temperature in drained and undrained plots.
- XV. Inspection of a proposed drainage district.
- XVI. Trip to concrete and clay tile plants.
- XVII. Make a blue-print from Plate III.
- XVIII. Practice in designing tile systems for wet areas in the field. Sketch plans to scale in field book.
- XIX. Apply water to glass cylinders filled with sand of different grades and note the rate of flow through each. Plan an experiment to determine the effect of confined air upon the rate of flow, and make a test. Use different heads of pressure, and note effect. Use constant head with different lengths of soil columns.
- XX. Cement and later paraffin one end of a concrete tile, and of a clay tile. Fill each with water and note the rate of loss. Repeat standing tile on end over a plane surface without ceiling. Is porosity desirable in tile?

- XXI. Place 2000 grams of fine, dry sand in a percolator, and shake down well. Saturate with water and let stand until it practically stops dripping. Determine the per cent of capillary water retained by drying 100 gram samples from each end of the soil column to constant weight. Would as much water be required to raise the water-table one foot as would be needed to raise it the second foot above an existing water-table?

APPENDIX
TABLE XXX*

VALUES OF COEFFICIENT c FOR USE IN KUTTER'S FORMULA

	r ft.	N = Coefficient of Roughness					
		.017	.020	.025	.030	.035	.040
$S = 1$ in 20,000 = .264 ft. per mile	1	^c 77	^c 64	^c 49	^c 40	^c 34	^c 29
	2	94	79	62	51	44	38
	3	104	88	71	59	50	44
	4	111	95	77	64	56	49
	6	122	105	85	72	63	56
	8	129	111	91	78	68	61
	10	134	116	96	82	72	64
	16	144	126	106	91	81	73
	20	149	131	110	96	85	77
$S = 1$ in 10,000 = .528 ft. per mile	1	81	67	52	42	35	31
	2	96	81	64	53	45	39
	3	104	89	71	59	51	45
	4	111	94	76	64	55	49
	6	119	102	84	71	61	54
	8	124	107	88	75	66	59
	10	128	111	92	78	69	62
	15	135	118	98	85	75	68
	20	139	122	102	89	79	71
$S = 1$ in 5000 = 1.056 ft. per mile	1	83	69	54	44	37	32
	2	97	82	64	54	45	40
	3	105	89	72	59	51	45
	4	111	94	76	63	55	48
	6	117	100	82	69	60	53
	8	122	105	87	73	64	57
	10	125	108	89	76	67	60
	15	131	113	95	82	72	65
	20	134	117	98	85	76	68
$S = 1$ in 2500 = 2.112 ft. per mile	1	85	70	55	45	37	32
	2	98	83	65	54	45	40
	3	105	89	71	59	51	45
	4	110	94	76	63	55	48
	6	116	99	81	69	60	53
	10	123	107	88	75	66	59
	20	131	115	96	83	73	66
$S = 1$ in 1000 = 5.28 ft. per mile	1	86	71	56	45	38	33
	2	98	83	66	54	46	40
	3	105	89	71	59	51	45
	4	110	93	75	63	54	48
	6	116	99	81	68	59	52
	10	122	105	87	74	65	58
	20	129	113	94	81	72	65

* From Trautwine's Engineers' Pocket Book.

TABLE XXX (Continued)
VALUES OF COEFFICIENT c FOR USE IN KUTTER'S FORMULA

$S = 1 \text{ in } 100 = 52.8$ ft. per mile	1	87	72	56	45	38	33
	2	99	83	66	55	46	40
	3	105	89	71	59	51	45
	4	109	93	76	63	55	48
	6	115	99	81	68	59	52
	10	121	105	86	74	65	58
	20	128	112	93	80	71	64
$S = 1 \text{ in } 2500 =$ 2.112 ft. per mile	$r \text{ ft.}$	$N = \text{Coefficient of Roughness}$					
		.013	.015	.017	.020	.025	.030
		c	c	c	c	c	c
	1	115	98	85	70	55	45
	2	130	112	98	83	65	54
	3	138	119	105	89	71	59
	4	142	124	110	94	76	63
	6	149	130	116	99	81	69
$S = 1 \text{ in } 1000 =$ 5.28 ft. per mile	10	157	138	123	107	88	75
	20	164	146	131	115	96	83
	1	116	99	86	71	56	45
	2	130	112	98	83	66	54
	3	138	119	105	89	71	59
	4	142	124	110	93	75	63
	6	149	130	116	99	81	68
$S = 1 \text{ in } 100 =$ 52.8 ft. per mile	10	155	136	122	105	87	74
	20	163	144	129	113	94	81
	1	117	99	87	72	56	45
	2	130	112	99	83	66	55
	3	138	119	105	89	71	59
	4	142	123	109	93	76	63
	6	148	129	115	99	81	68
	10	154	136	121	105	86	74
	20	161	143	128	112	93	80

TABLE XXXI
Released for use on June 15, 1931
DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS
WASHINGTON

U.S.
Dr-36

1930 CENSUS OF DRAINAGE
Preliminary Announcement: United States

Washington, D.C., June 15, 1931. — The Director of the Census today issued a statement showing some results of the 1930 drainage census for the United States and for 35 States where organized drainage enterprises are located. These figures are preliminary and subject to correction. The statement shows that the area in drainage enterprises in 1929 was 84,815,500 acres, which exceeded the area in drainage enterprises in 1919 by 19,320,462 acres, or 29.5 per cent. The drainage works included 139,437 miles of open ditches, 7,612 miles of levees and dikes, 90,331 miles of tile drains, and a large number of pumping plants. There were 67,713 enterprises with an investment of \$62,562,441.

State	Land in Drainage Enterprises in 1929 (acres)	Drainage Condition in 1929			Land in Occupied Farms		Capital invested in Enter- prises (dollars)	Open Ditches (miles)	Levees and Dikes (miles)	Tile Drains (miles)	Num- ber of Enter- prises
		Land Unfit for Crop Due to Drainage (acres)	Land Drained, Fit for Normal Crop (acres)	Land Partly Drained, Fit for Partial Crop (acres)	Total Land (acres)	Land planted in 1929 (acres)					
United States.....	84,815,500	7,451,249	66,398,518	10,777,733	69,105,453	55,107,483	632,562,441	130,457	7,612	60,231	67,713
Arizona.....	318,931	4,125	313,112	1,694	304,892	278,066	1,875,100	351	25	14	7
Arkansas.....	4,979,734	640,230	3,690,207	639,327	3,691,032	2,647,863	40,908,640	5,596	283	14	320
California.....	2,288,479	12,619	2,065,954	20,906	2,078,720	1,851,061	66,306,198	4,611	1,356	481	162
Colorado.....	5,236,266	28,740	272,180	28,348	281,396	248,392	4,359,016	813	756	369	149
Florida.....	5,811,760	1,390,562	1,974,613	2,446,585	483,850	37,816	1,916,423	4,470	75	4	58
Georgia.....	8,345	34,616	306,024	24,885	335,123	308,631	4,633,777	624	75	14	49
Illinois.....	5,034,122	275,960	4,511,451	249,771	5,002,880	4,265,524	74,333,065	5,992	1,107	4,325	1,918
Indiana.....	10,210,604	243,882	9,281,142	685,580	10,095,944	8,538,179	53,992,176	16,403	143	10,823	18,224
Iowa.....	6,248,189	76,991	5,981,543	229,655	6,138,189	5,294,339	42,901,383	14,403	343	12,972	5,785
Kansas.....	6,828,483	154,519	5,445,141	328,823	5,773,960	5,349,999	32,736,529	1,131	343	5	216
Louisiana.....	3,568,443	65,551	446,256	117,940	534,999	332,875	22,736,529	7,496	613	8	739
Michigan.....	9,119,568	542,403	7,511,572	1,065,593	8,555,036	6,475,839	37,994,410	14,145	909	5,777	10,677
Minnesota.....	11,357,693	2,037,964	7,202,413	2,117,596	8,660,555	5,883,537	53,507,692	14,145	1,447	9,611	2,844
Mississippi.....	2,967,538	253,834	2,418,969	286,035	2,106,283	1,752,174	23,397,913	4,277	227	43	84

TABLE XXXI (Continued)
DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS
WASHINGTON

U.S.
Dr-36

1930 CENSUS OF DRAINAGE
Preliminary Announcement: United States—Continued

State	Land in Drainage Enterprises in 1929 (acres)	Drainage Condition in 1929			Land in Occupied Farms		Capital invested in Enter- prises (dollars)	Open Ditches (miles)	Levees and Dikes (miles)	Tile Drains (miles)	Num- ber of Enter- prises
		Land Unit for Crop for Lack of Damage (acres)	Land Drained, Fit for Normal Crop (acres)	Land Partly Drained, Fit for Partial Crop (acres)	Total Land in 1929 (acres)	Land Planted in 1929 (acres)					
Missouri.....	3,459,866	368,971	2,733,009	388,798	2,650,721	2,246,550	46,392,782	5,658	940	123	364
Montana.....	157,520	6,385	132,871	8,370	150,844	114,298	1,579,296	284	284	76	27
Nebraska.....	865,559	9,705	820,339	33,515	848,329	734,618	6,919,538	1,187	413	92	132
Nevada.....	162,980	139	150,435	12,466	135,491	111,312	1,349,774	334	33	4	7
New Mexico.....	170,087	15,020	141,545	13,522	132,311	118,935	3,363,837	282	13	305	11
North Carolina.....	686,486	124,843	434,796	136,877	331,481	260,074	4,760,579	1,487	22	...	131
North Dakota.....	1,058,123	70,540	1,024,782	22,801	1,049,845	886,635	3,146,819	821	...	...	152
Ohio.....	8,147,508	117,089	7,466,253	664,166	7,892,225	6,748,152	36,650,018	23,480	20	12,100	26,069
Oklahoma.....	165,987	5,734	139,030	21,293	157,745	129,355	2,351,098	364	1	8	33
Oregon.....	294,432	30,625	146,856	27,291	141,826	109,763	4,546,457	475	121	42	52
South Carolina.....	203,433	31,002	137,737	34,694	95,302	62,657	1,594,526	431	11	6	30
South Dakota.....	690,007	26,266	615,897	48,054	676,395	571,703	4,524,868	782	...	315	205
Tennessee.....	603,392	144,384	363,819	95,689	414,152	213,486	6,412,246	1,457	29	...	192
Texas.....	2,866,356	215,617	2,785,417	455,222	1,890,254	1,272,762	12,116,332	3,824	215	...	87
Utah.....	156,062	5,600	142,941	7,511	110,029	87,871	2,772,000	304	10	1,944	32
Virginia.....	25,327	5,000	16,128	4,189	15,989	12,500	415,400	40	...	...	4
Washington.....	256,053	9,008	318,286	27,864	341,016	307,366	4,945,824	758	78	206	168
Wisconsin.....	867,947	137,093	542,232	198,632	552,876	351,196	6,336,704	1,878	9	...	305
Wyoming.....	246,203	9,821	221,962	17,439	179,127	154,015	5,106,573	517	...	223	26

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